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Recommendations for Chile´s Marine Energy Strategy – a roadmap for development

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Executive Summary

Introduction

The possibility of Chile producing significant amounts of renewable power from waves and tide has been gaining increasing national and international attention in recent years, fuelled by the levels of resource available in Chile, recent technological progress internationally and the vision, drive and commitment of certain organisations and individuals. The economic and regional development benefits of marine energy deployments are also increasingly widely recognised. Given the early development stage of wave and tidal power technologies, there are numerous challenges to be overcome before commercial projects can happen in Chile. Whilst this will take some time, there is a sense of urgency to define what the eventual contribution of marine energy to Chile´s energy mix might be, and what role Chile wishes to play in marine energy development in the interim.

This study combines knowledge of the energy situation in Chile with experience and understanding from more than a decade of marine energy activity internationally and specifically from Orkney in the UK, where 20 wave and tidal devices have been deployed and 11 commercial leases awarded. A lot has been achieved in the UK, but many lessons have also been learned. The aim of this project is to use this collective insight to propose steps that can help maximise Chile´s marine energy potential.

Chile´s energy situation

To deal with the competing pressures of rapidly increasing demand for energy and the imperative of reducing greenhouse gas emissions, energy use throughout the world will be revolutionised over the coming years. Chile is also faced with its own specific challenges such as relatively high and volatile electricity prices and comparatively low energy security as a result of dependence on fossil fuel imports (note the effect of reduced gas imports between 2005 and 2007 on cost in Figure 1). Reduced rainfall is also threatening the ability of hydroelectric power to provide base load electricity. Recent increases in demand have been met by coal and imported LNG, as shown in Figure 1.

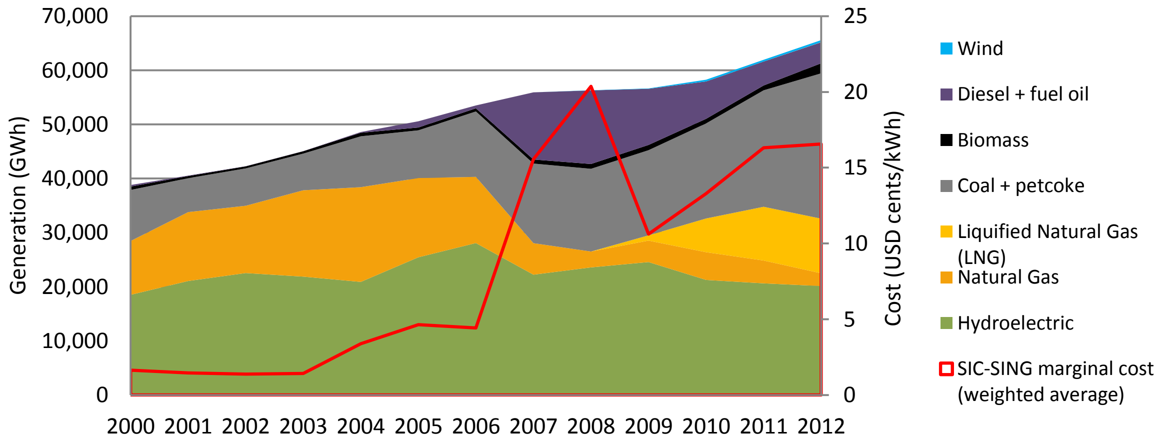

Figure 1: Generation mix and the cost of electricity in the Chilean spot market

The Chilean electricity market is deregulated and operates on a lowest cost model. Incentives and targets for Non-Conventional Renewable Energy (NCRE)[1] do exist (and have recently been increased); however, these are currently technology-neutral and not aimed at pre-commercial technologies such as wave and tidal.

[1] Defined by the Chilean Government as excluding large (>20MW) hydroelectric projects

Project methodology

This is a desk based study with extensive consultation and stakeholder engagement. The project has been organised so that it both gathers and disseminates information related to marine energy development. This project was developed in collaboration with the Ministry of Energy as an input to the ongoing development of marine energy strategy in Chile.

The core project team comprises individuals with a broad based involvement in marine energy developments around the world. This team has then been supported by a multidisciplinary group of specialists from within Chile who have an excellent insight into local processes and issues.

This project has brought together over 200 different organisations and individuals through workshops and interviews held in nine of Chile´s fifteen regions, to define recommendations for the development of marine energy in Chile. The project has also drawn on knowledge and experience from international marine renewable energy developments in some 15 countries and particularly from Orkney, Scotland and the UK which are probably the world's leading areas for marine energy development.

In early 2013, a register of stakeholders was agreed with the Ministry of Energy and other project partners. These stakeholders were then contacted, and notification of the project´s initiation was published on the Renewable Energy Centre (CER) website. Interested parties were invited to complete a preliminary questionnaire and to register to take part in a programme of consultation events.

Regional consultation workshops or interviews were held in nine of Chile´s fifteen regions (Figure 2). Thematic workshops were held covering the following areas:

- Finance and financial support mechanisms
- Regulatory framework
- Infrastructure and supply chain
- Electricity grid
- Environmental (through the Catholic University of Chile and FONDEF)
- RD&I (individual meetings with ten Chilean universities or applied RD&I centres)

Detailed input was received from the Chilean marine renewable energy association ADEMAR on a number of occasions, and that group was updated monthly on progress.

Region	Location
XV	Arica
I	Iquique
II	Antofagasta
V	Valparaíso
RM	Santiago
VIII	Concepción
X	Puerto Montt
XI	Puerto Aysén
XII	Punta Arenas

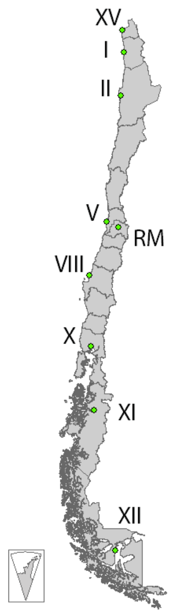

Figure 2: Consultation event locations

A delegation of officials from the Ministry of Energy, Renewable Energy Centre and Ministry of Environment went on a fact-finding mission to meet their opposite numbers in the UK and to visit Orkney and the European Marine Energy Centre to see marine energy devices in the water and better understand the associated issues and opportunities. In parallel to these activities, Aquatera and the project partners carried out a comparative study of international marine energy development to date and the potential in Chile. Finally, the results of the consultation events and comparative study were collated and analysed to form the content of this report.

Executive Summary

Why marine energy?

Scale

As has been shown in previous studies (E&A/UoE, 2012), (Garrad Hassan, 2009), Chile has a vast potential for generating power from waves and a much smaller but still significant tidal potential. Chile´s renewable energy resources dwarf the country´s current electricity demand (see Figure 3) and wave and tidal are increasingly recognised alongside other forms of renewables as sustainable alternatives to coal, diesel and gas-fuelled generation for an independent national energy supply.

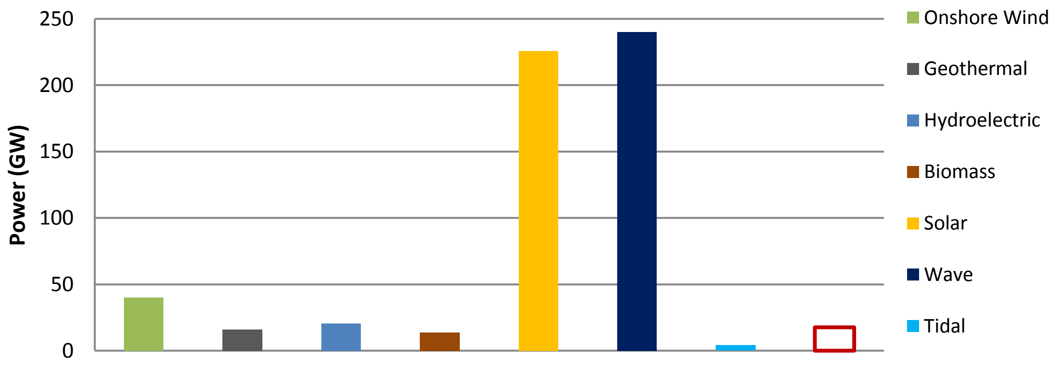

Figure 3: Chile´s total renewable energy resources compared to current total generating capacity (Sources: Renewable Energy Centre; Baird & Associates S.A.)

Wave energy is Chile´s largest renewable resource, totalling 240GW according to a study by Baird & Associates (Baird & Associates), and wave activity is high enough for power production on all Pacific-facing coasts. It could be argued that Chile is the best place in the world for wave energy, with over 4,000km of coast exposed to consistent high energy swells, and with all of the country´s energy demand located at or relatively near this coast. Average power levels range from around 20kW/m in the north of Chile to 50kW/m in Los Lagos. Further south, offshore energy levels are even higher, but projects would be more difficult in these relatively inaccessible areas with extreme operating environments.

Chile´s tidal energy resources are also significant but are perhaps one hundredth the size of the total wave resource. The largest tidal currents are found in the Magellan Strait (8-9 knot tides) and the Chacao channel (7 knot tides) near Puerto Montt, but further smaller tidal streams can be found at possibly 20 specific locations throughout the south of Chile. These resources have not been studied in detail and need to be better understood. As shown in Figure 4, waves and tides are denser sources of energy than wind and solar, so more power can be generated from a smaller area. Other characteristics are discussed below.

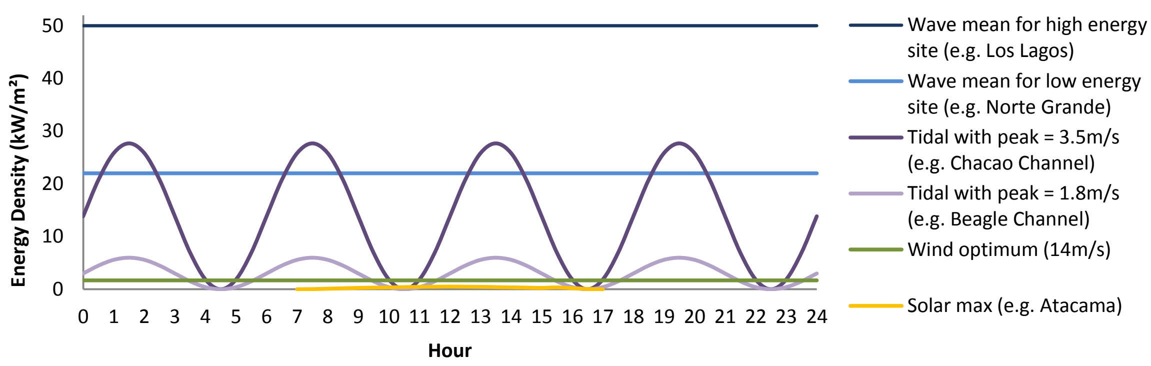

Figure 4: Idealised daily variation in energy density for Chilean renewable energy sources

Availability

A feature of many forms of renewable energy is variability in output over time, often expressed as a capacity factor[2]. Typical values for renewable energy sources in Chile are presented in Figure 5.

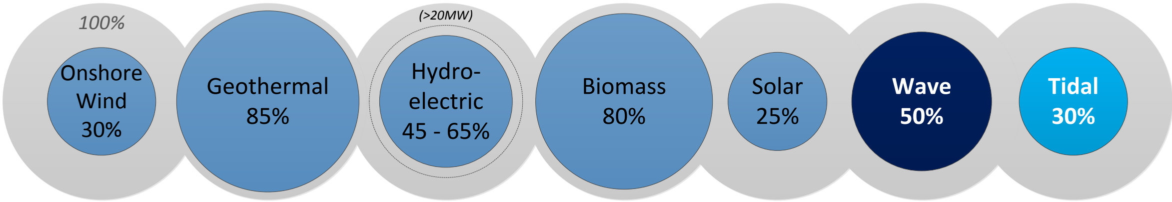

Figure 5: Typical renewable energy capacity factors in Chile (Sources: CER/Aquatera)

Capacity factors for wave power projects in Chile will be amongst the highest in the world because of Chile´s consistent waves (Monárdez, et al., 2008). This will however make marine operations to install and maintain devices more challenging. The timing and power levels of waves arriving at the Chilean coast can be forecast days in advance and often more accurately than, for example, wind speeds. Capacity factors for tidal generators will be lower as a result of the slack periods (typically four per day) when the direction of flow reverses around high and low water. As shown in , whilst wave and wind energy may be sustained (albeit varying) for days or weeks at a time, the energy available in tidal streams will hit zero while the flow reverses. The major advantage of tidal energy however, is that these variations are highly predictable.

Wave and tidal generators can produce power during hours of darkness (in contrast to solar output) and do not fluctuate at the same rate as wind output, but are not as controllable as hydroelectric output. Marine energy may therefore have some important advantages for balancing power requirements and could perhaps work in tandem with pumped storage systems. Marine energy resources are also found in many isolated coastal areas which currently have limited and costly access to energy and/or drinking water.

Current technology status

Wave and tidal power technologies are both at a pre-commercial stage of development and the cost of power from these sources is currently higher than Chilean electricity prices (see Figure 6). Tidal power technology is more developed than wave and is believed to have lower generation costs at present. This can be understood partly by comparing working principles. All successful tidal power devices make electricity from rotary turbines in flow. In this sense they are similar to wind turbines, and tidal power has been helped by technology transfer from that industry. The challenge of wave energy is to generate power from the low-speed and high-force oscillations of waves, which is a more complex problem with apparently a more diverse range of power conversion solutions.

The fact that marine energy has yet to be commercialised means that Chile has a chance to play a development role and establish a manufacturing capacity which would be difficult to achieve in more established industries such as wind and solar, where equipment is largely imported. There are specific areas of marine energy technology development which have received little attention to date and where Chile could play a leading role – for example in desalination, water pumping or the development of smaller systems for isolated communities. Serious progress in marine renewable energy technology started in the last ten years and a number of first generation technologies have completed or are nearing a decade of testing, with associated development costs of between 50

[2] The net capacity (or plant) factor of a power generator plant is the ratio of its actual to rated output over a period of time, typically a year. Note that capacity factors for solar (and other power plants) can be higher with energy storage.

and 100million USD per company. These development costs help to set the commercial cost of the technologies, but next generation marine energy devices are also emerging with significant cost savings and performance improvements. Possible costs of marine energy based on cumulative installed capacity deployed are compared to electricity costs in Chile in Figure 6.

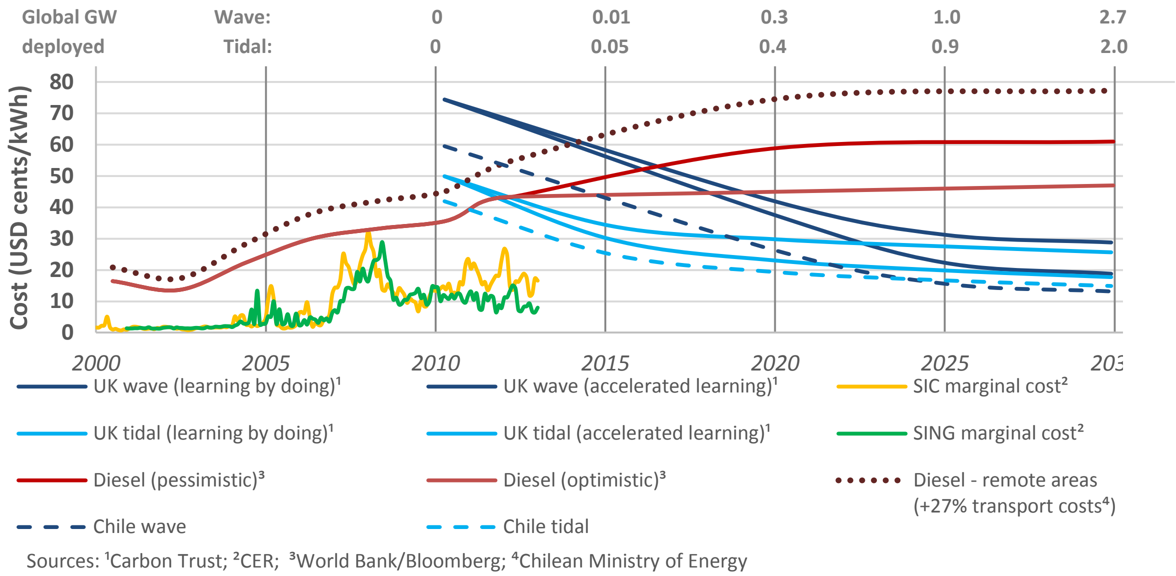

Figure 6: Historic electricity costs in the Chilean spot market (SIC/SING) compared to levelised cost of energy figures for diesel, wave and tidal power generation

Cost of energy

The balance between costs, revenue, business conditions and competitive alternatives will determine the commercial viability of a technology in a particular location. There are particular conditions in Chile that are worthy of note when considering this balance. Both the cost of energy from wave and tidal technologies and the commercial conditions may be quite different in Chile (as well as within the different regions of Chile). For example:

- Labour costs in Chile are lower than the UK and devices may be manufactured cheaper;
- General vessel, crew and diver rates are also lower in Chile than in many other areas;
- Various free trade zones and tax incentives exist in the extreme north and south of Chile;
- Chilean tidal sites are more protected from waves and floating or suspended debris (ice/trees/silt) than other sites internationally e.g. the Pentland Firth (UK) or the Bay of Fundy (Canada). This will tend to reduce structural, installation and maintenance costs;
- Installing and maintaining wave power devices could be more challenging than in the other areas due to near-constant wave action and steeply sloping seabeds, but increased production from the high energy wave climate will compensate for this to some extent.

Based on the comparative study of Chile and the UK carried out as part of this project, it is estimated that the cost of tidal energy may be 16% lower in Chile than in the UK (due mainly to reduced labour and standard vessel costs), and as much as 30% lower for wave energy (due to these factors and increased power production). Globally it is believed that the levelised costs[3] of wave and tidal energy will continue to fall as more devices are installed ("learning by doing") and innovation takes place ("accelerated learning")[4] as shown in Figure 6 (Carbon Trust, 2011). At the

[3] Levelised cost considers the capital, operational, maintenance and decommissioning costs of a project offset against energy production over the lifetime of a project.

[4] See report: Accelerating Marine Energy (Carbon Trust, 2011)

same time fossil fuel prices are likely to continue to rise, despite the recent influences of shale gas deposits on some gas prices. Another short term stabilising influence on the cost of electricity in the two main Chilean electricity grids is their planned interconnection in 2018. However, in the medium and longer term it is likely that an upwards price trend will continue, and certain that pressure to reduce carbon emissions will also increase.

On current trends, marine energy may be able to compete financially with other forms of renewables in the main electricity grid by the mid-2020s. Applications of marine energy where existing costs are higher (such as replacing diesel generation) or where power is used directly (such as seawater pumping) are likely to be viable earlier. Tidal power may already be competitive with diesel generation in some cases, particularly in remote areas (Figure 6).

The Ministry of Energy´s Marine Energy Strategy

The Chilean Government has published a National Energy Strategy for the period 2012-2030. The main pillars of this strategy are to increase the contribution from non-conventional renewables and to increase energy efficiency. The Ministry of Energy is now developing a marine energy strategy, with the following draft vision statement:

"The Chilean Government recognises the importance of developing renewable energy sources from Chile´s extensive marine resource in order to improve security of supply and mitigate climate change effects whilst contributing to the economic and industrial development of the nation.

To guarantee the maximum economic benefits associated with the use of the country´s marine energy resources, the Chilean Government wishes to establish a "Development Strategy for Marine Renewable Energy" which will allow the country to support the growth of the sector and take an active role in the development of marine energy in Chile´s territorial waters"

(Chilean Ministry of Energy, 2013)

It is encouraging that the Chilean Government has stated its preference for pursuing a development strategy, and that significant progress has been made towards this in the last year. The announcement of a total 27m USD of funding to create a marine energy centre of excellence and to support the first wave and tidal pilot projects is a very positive development, as are the various related studies and regulatory changes which the Chilean Government has implemented or proposed. Nonetheless, much remains to be done if Chile is to fully realise the benefits of developing a national marine energy industry. The aim of this project was to develop recommendations to help support the development of marine energy strategy in Chile. Recommendations are therefore structured around the pillars identified in the Ministry of Energy´s draft Marine Energy Strategy (Figure 7).

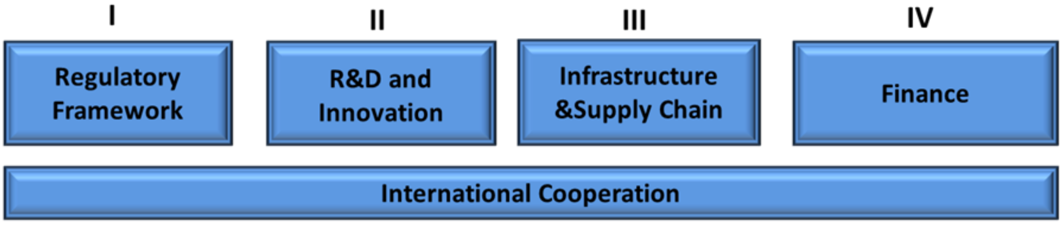

Figure 7: Pillars of the Ministry of Energy´s Marine Energy Strategy

Regulatory framework

Maritime concessions – *legal or commercial rights to use the sea/seabed*
The rules for obtaining maritime concessions for marine energy projects could be clarified, as could the impact of the proposed transfer of responsibility for these from SUBSECMAR (Ministry of Defence) to the Ministry of National Assets. The discussion around that legislative change presents an opportunity for marine energy related issues to be considered, and for a mechanism to be established which prevents speculative concession applications or resource hoarding. This has been a problem, to some extent, in the wind and solar sectors in Chile and also in the early commercial marine energy leasing rounds in Scotland/UK. A recent study carried out by Philippi Abogados considered marine energy developments of around 100MW size and concluded that the process of securing a maritime concession for such projects (in which multiple authorities are involved) was "slow, complex and uncertain" and could take at least one to two years to complete. Some Chilean device developers have however successfully deployed part-scale prototypes using the short-term concessions available for research or measurement purposes, but further consideration is required for projects of less than 100MW size that will be installed first.

Permits and licences – *the remaining permissions required, including planning consent, environmental impact assessment (EIAs), navigational permits, electrical concessions, etc.*
There is a lack of technical experience around permitting wave and tidal device deployments in Chile which has the potential to delay projects and be a barrier to the development of tailored marine energy regulations. Experience elsewhere in the world has shown that regulatory agencies can be ultra/excessively cautious when undertaking such work. A risk-based approach taking into account international experience is essential for evaluating early device deployments; otherwise projects can be delayed unnecessarily and incur excessive costs. Work has started to resolve this situation and in addition to the EIA guide being produced by the Ministry of Environment, it would be helpful to produce a manual for project developers which outlines the concession, permitting and licencing steps required to realise marine energy projects in Chile[5]. This project could also consider the potential for streamlining to minimise the number of licences required and regulators involved, and to enable coordinated consultation to reduce licence determination timescales.

Marine planning – *identifying and reserving the most appropriate areas for projects*
A national strategic environmental impact assessment should be considered in order to identify areas of the country with lowest environmental risk for marine energy projects. Combining this with the results of the planned infrastructure study and an evaluation of where marine energy projects can be implemented at lowest cost would enable priority development zones for wave and tidal energy to be identified in partnership with the regional and national commissions for coastline usage (CRUBC/CNUBC). It would be beneficial to grant voting rights for the Ministry of Energy representatives on these commissions, who currently have observer status only.

General
Setting up a health and safety working group tasked with creating a suitable risk management and control framework for Chile´s marine energy sector would be of benefit to the sector. It is important to learn from rather than copy existing regulatory provisions (either internationally or nationally from other sectors). Chile has a chance to set new and appropriate standards for marine energy that could become a model for other countries if the right balance is struck between control and facilitation. Renewable energy can provide an excellent opportunity for community engagement and even leadership with regards to project development and site selection.

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[5] Scotland has produced a Draft Marine Renewables Licencing Manual for this purpose, see: http://www.scotland.gov.uk/Resource/0040/00405806.pdf

Research, Development and Innovation (RD&I)

The Ministry of Energy and CORFO aim to consolidate Chilean research capacities and encourage the development of specialised devices and human capital through applied RD&I. The planned creation of an **International Centre of Excellence (ICE)** for marine energy is a key part of this, as are the various international partnerships which the Ministry of Energy has agreed. CONICYT and Chilean Universities may wish to consider coordinating Chilean research efforts with the international marine energy industry through partnerships with organisation such as the EERA[6] and projects similar for example to the UKERC marine energy research atlas (UKERC, 2012). CORFO may wish to consider a similar initiative for applied RD&I.

Technology cost reduction and adaptation is a stated priority of the Chilean Government and may be best focused on areas which require Chile-specific solutions. For example:

- Long wavelengths will influence the geometry of wave energy devices;
- High wave consistency requires new/more resilient installation and maintenance methods;
- Wave energy development areas on steep seabed slopes require new mooring designs;
- Seismic and tsunami risk must be considered;
- Synergies between tidal energy and run-of-river technologies could be usefully explored.

Support for the development and adaptation of foreign devices to Chilean conditions can be considered alongside the growth of new Chilean technologies. The goods and services that can be produced or provided in Chile could be identified and development in these areas encouraged.

The first steps towards understanding Chile´s marine energy resources have been taken, but Chile´s tidal resources need to be better understood. Mapping seabed bathymetry at high resolution in key resource areas and establishing the patterns of wave energy distribution near the coastline (<10km) would be beneficial. National assessments to date have considered only total marine energy resources, so further work to identify which sites are most economically viable is now needed and could be used to support the identification of priority development zones.

It is beneficial to prioritise environmental research based on experience to date, local sensitivities and risk/uncertainty. Baseline studies are required but should ideally focus upon features where there are likely and quantifiable effects. Of equal importance are the dissemination of information about marine energy and the benefits of such projects, to avoid conflicts due to lack of information.

There are a number of niche markets within marine energy which have received comparatively little attention to date where Chile may be able to take a leading role, including:

- Using wave energy to desalinate or pump seawater. The Chilean Government estimates that by 2020 the copper mining industry will require 6.3TWh of energy annually for these purposes alone.
- Developing small-scale marine energy systems for the thousands of isolated communities, salmon farms and tourist sites in Chile with limited or costly access to energy and/or water.

The activities of the planned **ICE** and **Wave and Tidal Pilot Projects** should ideally be linked together and coordinated with other similar centres internationally in order to transfer lessons learned and avoid duplicating efforts. It would be beneficial to define the extent to which these initiatives should be able to support future device deployments – for example by providing pre-permitted sites; access to installation tools; shared infrastructure or test facilities.

[6] European Energy Research Alliance, see http://www.eera-set.eu/

Infrastructure and supply chain

Electricity grid and routes to market

Chile is currently relatively well served by coastal electricity grid capacity, with around 50 possible connection points along its coastline. The grid is however comprised of 4 separate systems, the distance between connection points may be hundreds of kilometres and many of the more remote communities along the coast in Chile are not yet grid connected. The Ministry of Energy has confirmed that it plans to consider the electrical grid capacity requirements for marine energy, but no specific initiatives have been announced as of yet.

Marine energy projects in the UK and elsewhere have been delayed and even cancelled because of a lack of electrical grid capacity and onerous transmission charges. It is helpful to consider these problems and how they can be avoided in Chile. One solution can be exploiting markets which do not need grid connection for energy use i.e. off-grid communities but also energy applications such as desalination, water pumping and direct industrial use.

Infrastructure and supply chain

The Ministry of Energy plans to commission an infrastructure and services study for marine energy. The results of this study could be used to promote appropriate supply chain capacity building, the designation of priority development zones and the focusing of RD&I programs and other marine energy policies. It would be beneficial if the next port works plan by the Port Works Agency (Ministry of Public Works) could consider marine energy. It is important to consider the supply chain requirements for short term technology development (RD&I) alongside longer term and broader project development requirements which include survey, planning, manufacturing, installation and maintenance services, etc.

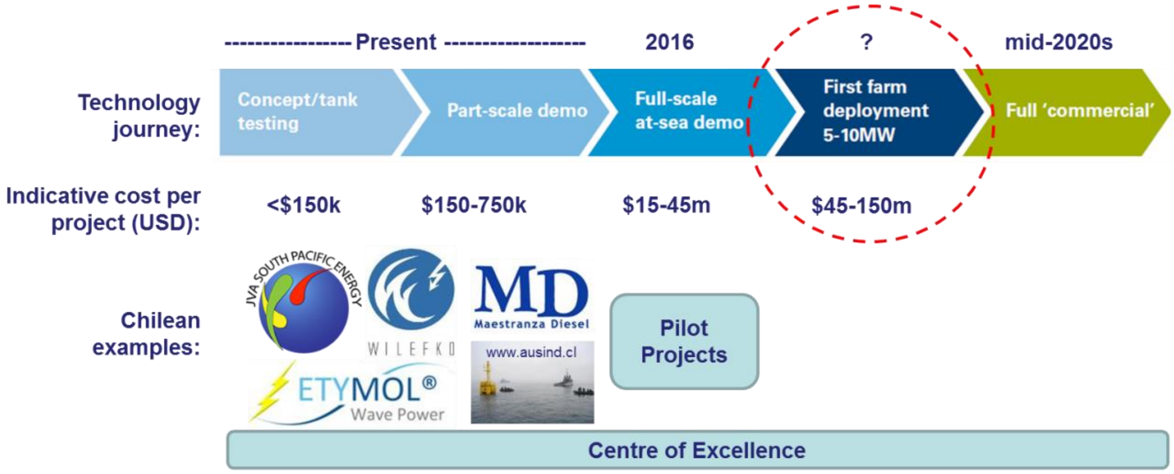
Strengthening links with international institutions already active in marine energy training would support building capacity in Chile. Chile Valora[7], the Ministry of Education and the Ministry of Labour may wish to consider including marine (or more generally, renewable) energy training in their programs.

Trade associations can be influential in promoting industry development, and those based in Santiago may wish to consider expanding their activities to those regions with greatest marine energy potential or partnering with existing local organisations.

[7] *Comisión Sistema Nacional de Certificación y Competencias Laborales,* the National Commission for Certification and Labour Skills

Finance

Given the early stage of sector development, finance is a key enabling issue. Increased risk awareness and tighter credit controls have made it more difficult to raise funds in recent years. Relatively minor government support can be used to leverage significant private sector investment.



Note: Chilean technology developer examples are not in any particular order.

Figure 8: Technology journey – based on (Carbon Trust, 2011)

Chile´s renewable energy (NCRE) incentives are not aimed at pre-commercial technologies but do influence prices for renewables in the marketplace. Other existing funds and RD&I incentives have been sufficient to support some Chilean companies to test part-scale prototypes and for various university projects and other studies. The planned 27m USD of funds for pilot projects and an ICE is a change in the level of investment which should ensure the first large at-sea deployments and a continued level of applied RD&I activity (see Figure 8).

Several countries continue to offer generous subsidies for generation that are unlikely to be replicated in Chile. Rather than seeking to compete with the support available internationally for MW-scale grid connected farms, Chile may wish to consider supporting projects in niche markets.

For a development strategy to be fully realised, additional support for pre-commercial projects which allow Chile to take a more active role in marine energy development would be required. As shown in Figure 8, with the financial support mechanisms currently available there is the potential for a gap in activity between the end of the funded phase of the pilot projects and the onset of commercially viable projects. A broader base of support could be established. It may be possible for Chile to pursue a development strategy without subsidising large scale pre-commercial deployments, in particular by:

1. Supporting RD&I projects which reduce technology risk and bring down costs – this must be coordinated with the global marine energy industry but should also support Chilean technology developers.
2. Creating new studies and funding instruments to support the development of niche markets within marine energy where Chile has natural advantages or a significant home market, for example in wave-powered desalination and water pumping for the mining industry or energy/water systems for isolated communities or salmon farms.
3. Maintaining some activity in the more conventional area of MW-scale grid connected prototypes, through the development of a new funding instrument to support for example an expansion of the planned wave and tidal pilot projects to include multiple devices (say 10 to 30MW capacity) in the medium term e.g. around 2020.

Regional analysis

Chile is a vast country with over 4,000km of coastline. Some of Chile´s fifteen regions are of comparable size to mainland Scotland, and marine energy policy must take this exceptional geography into account.

Norte Grande / Norte Chico

In the north of Chile, water and energy demand could drive the development of (possibly combined) wave power, desalination and seawater pumping plants. Demand in all of these areas is expected to rise due to continued growth in mining activity. High energy and water costs combined with tax benefits and a more benign operating environment could make wave energy projects viable earlier here than in the south. Fossil fuels make up 99% of the energy mix, so there is a pressing need to increase the contribution from non-conventional renewable energy in the grid. It is also understood for example that close to half of the isolated communities in Antofagasta region rely upon water tankers and the potential for community scale wave-powered desalinaton merits investigation.

Centro / Centro Sur

The central zone of Chile is likely to play a key role in the development of the country´s marine energy supply chain – device structures and components could be manufactured here. Collaborative planning between the private and public sector is required to promote the development of local industry. Given the high population density and intensity of coastal use in this zone, perhaps the most urgent challenge is to identify and reserve areas with potential for wave energy. Population density towards the south is lower, but wave energy levels are higher. Large seabed areas of suitable depth are available, and as projects can connect to the central Chilean electricity network (*Sistema Interconectada Central*, SIC) the potential for commercial wave energy farms in Los Lagos is high. Industrial and supply chain capacity is also strong in these areas.

Los Lagos

Los Lagos is a strategically important region of Chile as it possesses both wave and tidal resources in abundance. This region is a transition zone between the most populous areas of Chile and the Patagonia south. There are many isolated communities scattered among islands, fiords and channels. Energy costs (usually from diesel generation) are high, so there is interesting potential for renewables, including wave and tidal. The Chacao channel is the second most important tidal stream in Chile after the Magellan Strait, and projects here would be able to connect to the SIC. Effort will be however required to design a project which is environmentally and socially acceptable in this sensitive area; a coastal but onshore wind project in Chiloé was recently held up due to perceived risk of impacts on blue whales and archaeological heritage.

Aysén, Magallanes and offshore islands

There are some significant tidal streams in Aysén in proximity to isolated communities, salmon farms or tourist sites. Magallanes is home to Chile´s largest tidal resource in the Magellan Strait, but there are also many smaller sites with good potential, such as the Beagle and Fitzroy channels. These resources need to be better understood (as does the run-of-river potential). Although wave energy levels on the Pacific coast are extremely high in Aysén and Magallanes, these are relatively inaccessible and unlikely to be developed for the foreseeable future. Smaller wave power projects in lower energy sites such as the north of Aysén or wider parts of the Magellan Strait or Seno Otway may however be possible. The marine energy potential of Chile´s offshore islands and in particular Easter Island and Juan Fernandez is also interesting. Chile´s Regional Governments and the Subsecretary of Regional Development may wish to consider the potential for drinking water and energy supply from marine renewables as part of their strategies for remote communities. It would be beneficial to identify the most promising sites, in coordination with the regional coastline use commissions (CRUBC).

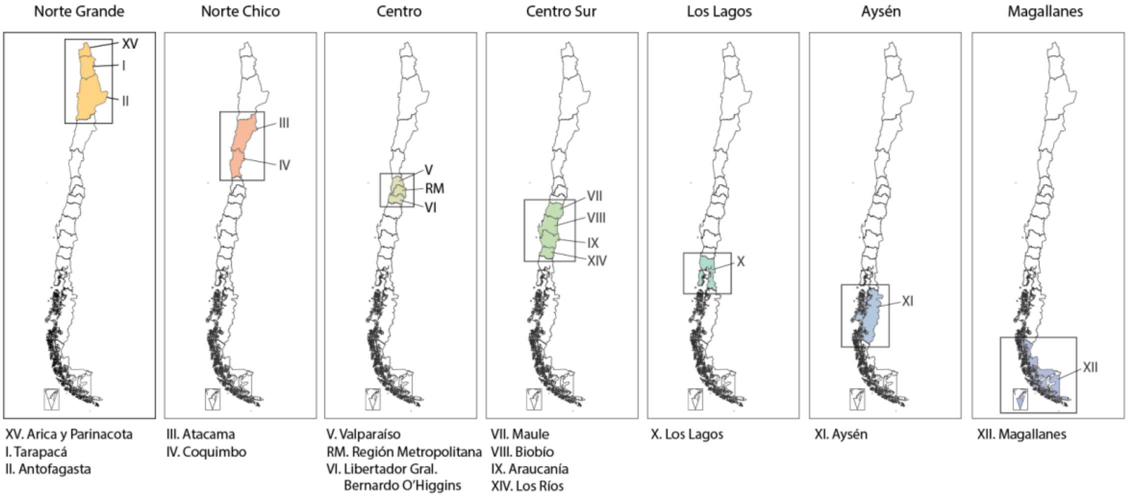


Figure 9: Marine energy regions

There is interesting marine energy potential in each one of Chile´s fifteen regions. This study considered the characteristics of the marine energy regions shown in Figure 9 in order to identify the most likely priority areas for each. Table 1 presents a summary of the conclusions from this work.

Table 1: Regional priorities for marine energy development

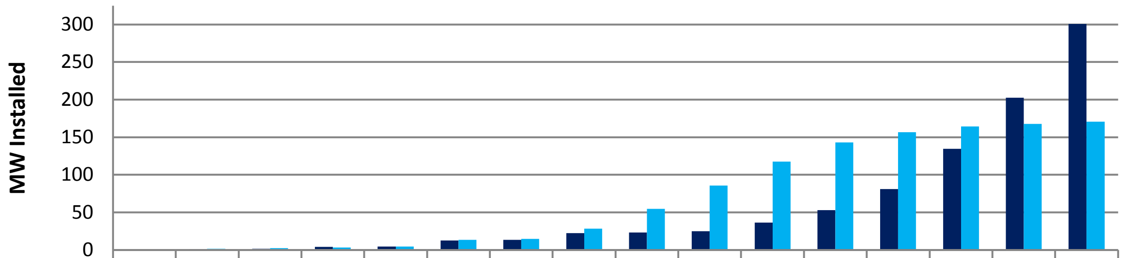
Key:	Good potential	Some potential	Little or no potential

	Norte Grande & Chico	Centro & Centro Sur	Los Lagos	Aysén	Magallanes	Offshore islands
Technology						
Small scale and off-grid tidal projects	Little or no potential	Little or no potential	Good potential	Good potential	Good potential	Some potential
Multi-MW tidal projects and farms	Little or no potential	Little or no potential	Good potential	Some potential	Good potential	Little or no potential
Small scale and off-grid wave projects	Good potential	Good potential	Good potential	Some potential	Some potential	Good potential
Multi-MW wave projects and farms	Good potential	Good potential	Good potential	Little or no potential	Little or no potential	Little or no potential
Device manufacture	Some potential	Good potential	Some potential	Some potential	Good potential	Little or no potential
Energy markets						
Electrical grid and direct industrial use	Good potential	Good potential	Good potential	Some potential	Some potential	Some potential
Desalination / water pumping (mining)	Good potential	Some potential	Little or no potential	Little or no potential	Little or no potential	Little or no potential
Community desalination	Good potential	Some potential	Little or no potential	Little or no potential	Little or no potential	Good potential
Community energy	Good potential	Good potential	Good potential	Good potential	Good potential	Good potential
Salmon farms	Little or no potential	Little or no potential	Good potential	Good potential	Good potential	Little or no potential

Development scenarios

The cost of marine energy will fall as more devices are installed around the world and as innovation takes place. The point at which projects become commercially viable in Chile will depend to a large extent on cost reduction efforts taking place outside of Chile and on future energy costs which are uncertain. It is not possible to say how future developments will take place, but it is clear that government support at the pre-commercial stage can increase installation activity and hasten the onset of commercial projects.

As tidal power technologies are closer to commercialisation, it is probable that more tidal than wave power capacity will be installed initially. There are however a limited number of tidal sites and once commercialised, wave power will be able to continue to grow more rapidly (Figure 10).



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
WAVE	0.1	1.3	1.7	4.1	4.5	12.8	13.6	22.4	23.2	24.8	36.4	53	81.2	134.4	202.6	300.8
TIDAL	0.4	1.8	2.6	3.4	4.6	13.3	14.9	28.5	54.5	85.5	117.5	143	156.5	164.5	167.5	170.5

Figure 10: Potential wave and tidal energy development scenario for Chile

In the analysis undertaken, current Chilean marine energy policy constitutes a **deployment plus strategy** scenario where regulatory changes are made and an increase in RD&I activity is supported, but device installations may be limited until the advent of commercial projects, probably by the mid-2020s. If further pre-commercial support can be made available, for example to support market niche projects in the short term and perhaps a 10-30MW expansion of the pilot projects in the medium term, this would constitute a **development strategy** sufficient for Chile to reap the economic benefits (jobs and investment) associated with an active role in marine energy development. In the most optimistic scenario shown below, support for multiple pre-commercial farms would guarantee a leading role for Chile through an **accelerated development strategy**. Figure 11 compares these three scenarios to historic growth in Chilean onshore wind and biomass capacity and forecasts for the growth of marine energy in the UK.

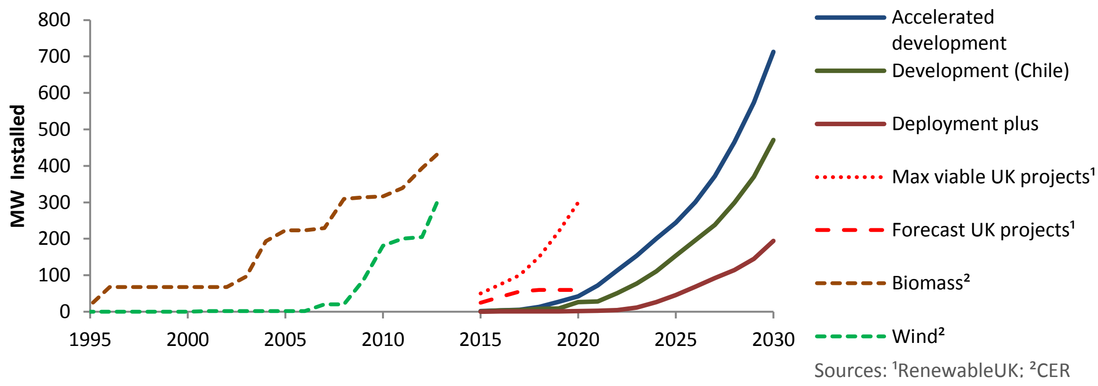


Figure 11: Historic growth in onshore wind and biomass in Chile compared to forecast scenarios for marine energy in Chile and the UK

Key recommendations

This project aimed to develop a series of specific recommendations to support the development of marine energy strategy in Chile. Table 2 presents a summary of these recommendations. The details and reasoning behind these are presented in the main report.

Table 2: List of key recommendation

Activity Categories:	Regulatory	RD&I	Infra. & Supply	Finance

Page	Activity	Activity Category	Timescale
57	Establish International Centre of Excellence (ICE) to lead on strategic national research projects; create national plan for marine energy RD&I.	Ministry of Energy (MoE)/ CORFO	Urgent
56	Implement pilot projects and agree coordinated objectives for these projects with the ICE.	Ministry of Energy	Urgent
28	Develop robust marine energy strategy, appoint independent steering group to review, advise and publish progress bi-annually.	Chilean Government	Urgent
18	Develop clear rules for maritime concessions; reduce uncertainty around transfer of powers from SUBSECMAR to Min. National Assets.	MoE / Defence / National Assets	Urgent
8	Integrate renewable energy policy with wider energy, economic and regional development policies. Consider novel energy uses.	Chilean Government	Ongoing
57	Hold regular marine energy RD&I conferences; publish findings.	Academia; Industry	Ongoing
70	Hold regular supply chain conferences; strengthen trade bodies/energy associations and expand these regionally.	Academia; Industry	Ongoing
71	Establish renewable energy skill gaps and tackle these. *Also Ministry of Labour, Ministry of Energy and Industry.	Ministry of Education* and Academia	Ongoing
25	Grant Ministry of Energy voting rights on CRUBC & CNUBC.	CNUBC / MoE	Short-term
27	Complete national strategic environmental impact assessment (SEIA) for marine energy.	Ministry of Environment	Short-term
11	Map distribution of tidal resources in Chile.	MoE / CER	Short-term
86	Support RD&I, feasibility studies and create funding new mechanisms for small scale projects, desalination and water pumping applications. Support Chilean technology developers.	Ministry of Energy / CER	Short-term
57	Formalise links with international marine energy forums (UKERC/EOEA).	Industry / Academia	Short-term
22	Develop a manual (or otherwise clarify) permits and licences required for marine energy projects; consider streamlining.	Renewable Energy Centre (CER)	Short-term
26	Identify and designate priority zones for development through consultation and using results of the SEIA, infrastructure and cost of energy studies; include marine energy in regional coastline use plans.	MoE / CNUBC / CRUBC	Short-term
43	Prioritise environmental research impact assessment using a risk-based approach considering international experience; create an environmental working group to coordinate environmental marine energy research.	Academia / MoE	Short-term
61	Study grid connection requirements, costs and timescales for marine energy and create development plan.	MoE / CDEC	Short-term
57	Draw up a plan for applied and fundamental marine energy RD&I.	CORFO; CONICYT	Short-term
40	Gather measured data on marine energy resources and seabed bathymetry.	Industry / Academia	Short/ medium
64	Use results of infrastructure study to create and maintain national/regional infrastructure and supply chain plans.	Ministry of Energy and others	Short/ medium
86	Create new financial instrument for 10-30MW expansion of pilot projects by 2020.	Ministry of Energy	Medium-term
19	Establish leasing process for commercial farms. *With Ministry of Defence and/or Ministry of National Assets.	Ministry of Energy*	Medium-term

Common acronyms used in this report

ADEMAR	*"Associación para el Desarollo de Energias Marinas en Chile"* – Chilean Marine Energy Association
CDEC	**"***Centro de Despacho Económico de Carga"* – Centres of Energy Despatch, grid operators of SIC and SING electricity networks (see below)
CER	**"***Centro de Energías Renovables*" – Renewable Energy Centre
CNUBC	*"Comisión Nacional de Uso de Borde Costero"* – National Commission for Coastline Use
CRUBC	*"Comisión Regional de Uso de Borde Costero"* – Regional Commission for Coastline Use
CONICYT	*"Comisión Nacional de Investigacion Cientifica y Tecnologica"* - National Science and Technology Research Commission, Ministry of Education
CORFO	*"Corporación de Fomento de la Producción"* - Economic Development Agency, Ministry of Economy
DIPRIDA	*"Dirección de Investigación, Programas y Desarollo de la Armada" -* Directorate of Research Programmes and Development of the Chilean Navy (Ministry of Defence)
DIRECTEMAR	"*Dirección General del Territorio Marítimo y de Marina Mercante"* – Directorate of Maritime territory and Merchant Marine, Chilean Navy (Ministry of Defence)
FONDECYT	*"Fondo Nacional de Desarollo Científico y Tecnológico"* – National Science and Technology Development Fund, part of CONICYT (Ministry of Education)
FONDEF	*"Fondo de Fomento al Desarrollo Scientifico y Tecnológico"* - Scientific and Technological Development Fund, Ministry of Education
EMEC	European Marine Energy Centre
ERNC	*"Energías Renovables No Convencionales"* – Non Conventional Renewable Energy (see NCRE below)
ICE	International Centre of Excellence
InnovaCORFO	Innovation arm of CORFO
NCRE	Non-Conventional Renewable Energy. In Chile, Law 20.257 considers as NCRE all renewable energy plants with the exception of hydroelectric power over 20 MW size.
RD&I	Research, Development and Innovation
ROC	Renewable Obligation Certificates, a UK market-pull subsidy for renewables.
SHOA	"Servicio Hidrográfico y Oceanográfico de la Armada" - Hydrographic and Oceanographic Service of the Chilean Navy
SIC	*"Sistema Interconectado Central"* – Chile´s central electricity grid
SING	*"Sistema Interconectado del Norte Grande"* – Chile´s northern electricity network
SUBSECMAR	*"Subsecretaría de Marina"* - Sub-secretary of the Chilean Navy (Ministry of Defence)

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1 Introduction

1.1 Background context

In March 2012, a review of the potential for developing marine energy in Chile was published (E&A/UoE, 2012). That report summarised Chile´s marine energy resources and gave an overview of the development stage of various marine energy technologies around the world. In addition, the report identified and compared a number of models for consenting and financing within the marine energy sector. Finally, the report outlined potential strategies for the Chilean Government to support the marine energy sector. One of the public policy proposals made in this report was for stakeholders to be brought together to develop a roadmap for marine energy in Chile.

Since the publication of that 2012 report, the Chilean Ministry of Energy has begun developing a marine energy strategy, the first version of which is due to be published in 2014. This roadmap project formed part of the consultation process to support the development of that strategy.

1.2 Aim

The aim of this project was to propose recommendations which help fulfil the Chilean Government´s vision for marine energy, based on international experience and extensive local research and consultation. It is hoped that this final report will support the ongoing development of a detailed marine energy strategy for Chile.

1.3 Project team

This project has been undertaken by Aquatera Ltd, supported by a group of Chilean associates. Aquatera is headquartered in Orkney, Scotland and has established a global reputation as one of the leading consultancies and applied research organisations in the marine energy sector. Aquatera became actively interested in the marine energy potential of Chile in 2008/2009 and since that time has made numerous visits to Chile and hosted a number of delegations from Chile in Orkney. Recently, Aquatera established a local team in Chile with the view of creating a permanent presence in the country.

Aquatera staff have worked in the marine energy sector since 1987. The company has completed over 250 projects related to marine energy developments and associated infrastructure. Aquatera has worked for technology developers; commercial project developers; supply chain companies; grid companies; port authorities; boat operators; conservation agencies; economic development agencies; local governments; national governments and international organisations.

Aquatera and the company´s sister organisation Orcades Marine Management Consultants have provided design and operations support to marine technology companies, test site developers and commercial project developers. Aquatera and Orcades Marine have worked for over 30 marine technology companies, providing a wide range of research, design, surveying, permitting, deployment, monitoring and public communications services – and managing more than 1,000 days at sea undertaking survey, deployment and marine energy technology monitoring and recovery works.

The core to Aquatera's research and services lies in the relationships between projects and their operating environment. Aquatera is based in Orkney, at the heart of the world´s emerging wave and tidal industry, and Aquatera staff and associates ensure that the opportunities associated with marine energy development are fully exploited and that this development takes place to the highest standards of environmental stewardship.

One of the foundations to Aquatera´s approach has been seeking to work with local experts and specialists in strong partnerships. In this project, Aquatera was assisted by the following Chilean partners:

RODA Energía is a consultancy and energy engineering firm based Chile´s capital, Santiago. The company has significant experience in renewable energy project finance and financial support measures. RODA Energía provides support to clients navigating the Chilean regulatory system and facilitates public-private events and networking in Chile´s energy sector.

Alakaluf specialises in oceanographic technology and marine renewables. The company is based in Punta Arenas, in Chile´s southernmost Magallanes region, and has extensive experience in installing and operating technology in harsh Patagonian conditions as well as in carrying out detailed studies of the local environment and marine energy resources. In addition to strong links with the local community, Alakaluf has partnerships with a number of international marine energy companies.

BZ Naval Engineering is a naval and maritime engineering services company based in Santiago. The company has a track record with the Chilean Navy and provides services ranging from marine inspections and insurance warranty work through to logistics and marine project management. BZ Naval Engineering also represent international marine energy device developers in Chile.

ON Energy are electricity grid and market specialists with an in-depth understanding of Chile´s electricity infrastructure and market. The company´s expertise includes areas such as taxation in transmission systems, contract negotiation for power purchase agreements, electrical system planning and regulation.

Bringing together this team of experts from different sectors of Chilean industry enabled Aquatera to carry out a broad consultation and develop specific and achievable recommendations for Chile´s marine energy strategy.

1.4 Methodology

The approach agreed for this project was to combine the knowledge and experience from within Chile with knowledge and experience from international marine renewable energy developments and particularly from world's leading area for marine energy development, namely the waters around Orkney, across Scotland and more widely in the UK.

Information and understanding from within Chile has been collated through an extensive series of individual and group interviews and workshops. This has involved an unprecedented level of engagement with government, industry, academia and others with an interest in marine energy development. A total of more than 200 organisations and individuals were consulted.

In early 2013, a register of stakeholders was agreed with the Ministry of Energy and other project partners. These stakeholders were then contacted, and notification of the project´s initiation was published on the Renewable Energy Centre (CER) website, so that any interested parties could fill in a preliminary questionnaire and register to take part in a programme of consultation events, which was tailored to the responses received.

Regional consultation workshops or interviews were held in nine of Chile´s fifteen regions (see map opposite) and thematic workshops were also held covering the following areas:

- Finance and financial support mechanisms
- Regulatory Framework
- Infrastructure and supply chain
- Electricity grid
- Environmental (through the Catholic University of Chile and FONDEF)
- RD&I (individual meetings with eight Chilean universities and applied research centres)

Detailed input was received from the Chilean marine renewable energy association ADEMAR on a number of occasions. Members were updated monthly on progress and their feedback sought.

Region	Location
XV	Arica
I	Iquique
II	Antofagasta
V	Valparaíso
RM	Santiago
VIII	Concepción
X	Puerto Montt
XI	Puerto Aysén
XII	Punta Arenas

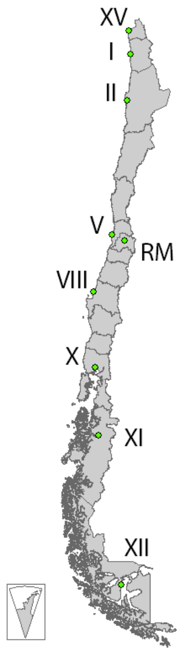

Figure 12: Consultation event locations

A delegation of officials from the Ministry of Energy, Renewable Energy Centre and Ministry of Environment were supported on a fact-finding mission to meet their opposite numbers in the UK and to visit the European Marine Energy Centre and see marine energy devices in the water.

In parallel to these activities, Aquatera and the project partners carried out a comparative study of international marine energy development to date and the potential in Chile.

Finally, the results of the consultation events and comparative study were collated and analysed to form the content of this report.

This report deals with wave and tidal power separately where appropriate. Other forms of marine renewable energy such as offshore wind or ocean thermal or salinity gradient are not considered.

1.5 Report Structure

The structure of this report is determined to a large extent by the structure of the draft marine energy strategy which this report aims to support. The topics of the chapters are laid out below:

- Overview
- The Chilean Ministry of Energy´s marine energy strategy
  - I - Regulatory framework
  - II - Research, development and innovation (including marine energy centres)
  - III - Infrastructure and supply chain
  - IV - Finance
- Analysis of marine energy regions
- Investigation of possible development scenarios
- Recommendations
- Conclusions
- References

The overview chapter gives a brief introduction to Chile´s energy sector and the state of marine energy development, with an assessment of the main opportunities and challenges facing the industry today. The key elements of the Ministry of Energy´s marine energy strategy are then presented and a discussion of appropriate marine energy policy is structured around the four strategic pillars identified by the Chilean Government (I to IV above).

The following chapter focuses on the marine energy potential of the different regions of Chile and provides maps of the marine energy resources and relevant infrastructure in each region.

A number of possible development scenarios are then investigated and the potential effect of government strategy is considered.

Finally, the report presents the recommendations and conclusions from the project.

The main report is supported by a number of case study examples provided within text boxes as shown below:

Case study X: title (location)

Explanatory narrative and lessons learned.

Throughout this report, various recommendations are made report based on the information that has been presented and the results of the consultation. The format for these recommendations is shown below:

Recommendation X: title

Short narrative explaining the action or approach suggested, **responsible organisation(s)** and why it is believed this approach may be beneficial.

Possible action holder(s) **Timescale of recommendation**

Note: Case studies and recommendations are numbered by chapter e.g. the first recommendation in Chapter 2 is Recommendation 2-A, etc.

Recommendations and analysis are developed based on the timescales shown below, where in general “short term” signifies the next five years and “long term” is considered post-2025.

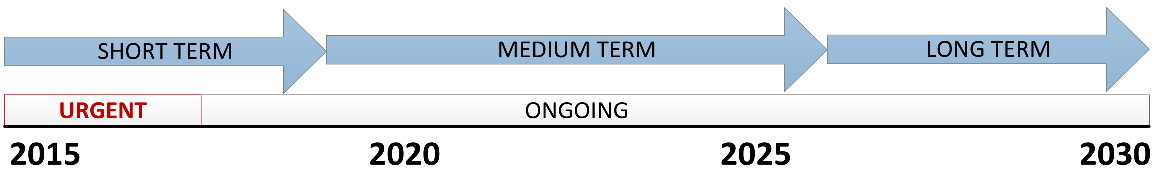

Figure 13: Timescales referred to in this report

Some of the more important short term recommendations are marked “urgent”. Recommendations which relate to actions that have already started but require continuing attention are marked “ongoing”.

2 Overview

The following vision statement from the Ministry of Energy´s marine energy strategy green paper demonstrates the interest and commitment to marine energy in Chile:

"The Chilean Government recognises the importance of developing renewable energy sources from Chile´s extensive marine resource in order to improve security of supply and mitigate climate change effects whilst contributing to the economic and industrial development of the nation.

To guarantee the maximum economic benefits associated with the use of the country´s marine energy resources, the Chilean Government wishes to establish a "Development Strategy for Marine Renewable Energy" which will allow the country to support the growth of the sector and take an active role in the development of marine energy in Chile´s territorial waters"
(Chilean Ministry of Energy, 2013)

The adoption of such a forthright government vision has been prompted by a number of factors, in particular:

- Chile´s growing need for clean, secure and economic energy supplies;
- The scale of Chile´s wave, and to a lesser extent tidal, energy resources;
- The potential to create jobs and attract investment by developing a local industry; and recent profile-raising studies, events and visits by key Chilean personnel to existing centres of marine energy development.

Significant progress has been made recently towards fulfilling the vision outlined, but there is much still to be achieved. This report seeks to review progress and make recommendations on the steps required to maximise Chile´s marine energy potential.

2.1 World energy situation

Energy use throughout the world is set to go through a revolution over the coming years. This revolution must deal with the competing pressures of rapidly increasing demand for energy and the imperative of reducing greenhouse gas emissions to minimise the scale of global warming. Issues that will be critical to meeting these goals include:

- Introducing and improving energy efficient low carbon technologies in order to diversify the energy mix and meet growing energy demand;
- Altering the relationship that mankind has with energy, making it a more valued commodity, with full awareness of lifecycle consequences and with lifecycle costs paid for by consumers.

Renewable forms of energy capture for electricity and other uses will play a critical role in this complex energy revolution.

2.2 Chile´s power sector

In the period from the mid-70s to the early 90s Chile undertook a series of reforms to restructure, deregulate and privatise its electricity sector, with the goal of creating an attractive climate for investment. The reforms started with the dismantling of two public utilities into seven generation, eight distribution and two transmission companies. The sector was then deregulated and privatised over a period from around the mid-1980s to the early 1990s.

The 1982 General Law on Electric Services, which instituted the reforms, created an electricity supply industry based on the principle of competitive generation and supply, with a pool-type electricity market and a system operator. As per the law, distribution and transmission were considered natural monopolies resulting in investment requirements, third-party access and prices for access to and use of the networks remaining regulated.

Generation, transmission and distribution in Chile are unbundled horizontally, but integrated vertically, with generators owning transmission and distribution assets. There are many players in generation, transmission and distribution, but the majority of assets in all 3 sectors are still owned by a small number of companies, with Endesa, AES Gener and Colbún being the three largest.

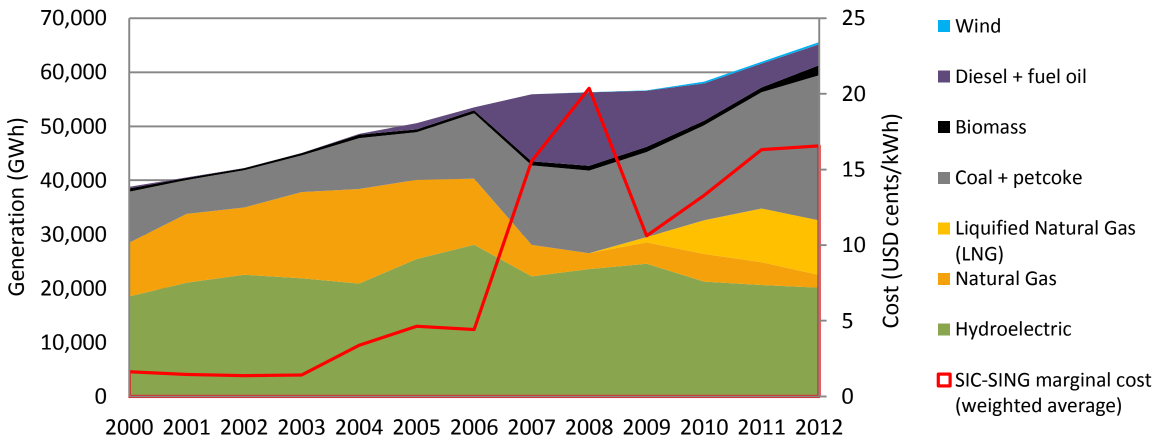

Figure 14: Generation mix and average marginal cost in Chile´s central (SIC) and northern (SING) electrical systems (Source: Ministry of Energy, CDEC-SIC and CDEC-SING)

The Chilean electricity supply is heavily dependent on imported fossil fuels (see Figure 14) and variable hydroelectric reservoir levels. Both these factors result in high and volatile electricity prices in Chile. Chile´s high dependence on Argentinean gas led to an energy crisis during 2000-2005 when Argentina repeatedly interrupted the contracted gas supplies. The Argentinean gas crisis has been a major factor in shaping the subsequent Chilean energy market strategy and increasing focus on energy independence and security of supply.

Chile´s strong economic growth has led to ever-rising demand for electricity with demand set to more than double by 2030 – see Figure 15 below. In its latest energy strategy for 2012-2030 the Chilean Government put a strong emphasis on using renewable energy to meet a significant part of this growth.

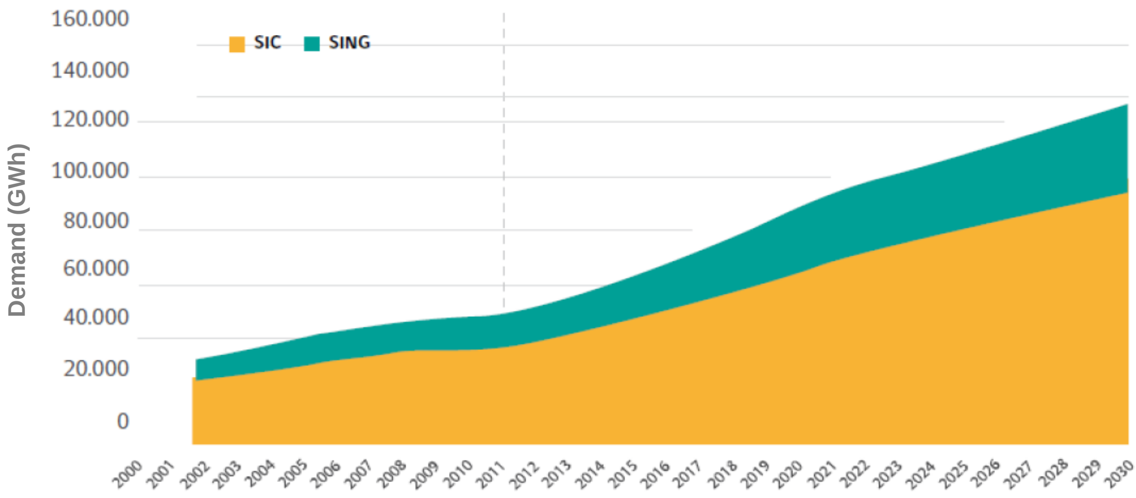

Figure 15: Forecast annual electricity demand in Chile´s central (SIC) and northern (SING) electrical systems (Source: CNE / Ministry of Energy)

As well as electrical energy demand there are important energy requirements for transport, industrial processes, agriculture, domestic heating, etc. These forms of energy use offer equally important opportunities for alternative supplies and the creation of new energy markets.

Recommendation 2-A: Integration of renewable energy policy with wider energy, economic and regional development policies; consider novel energy uses

When examining the markets for energy and trends of energy use, it is beneficial to include statistics on electrical and non-electrical energy. This means that energy markets such as transport, water pumping, desalinisation and off-grid supply can be included along with grid supply of electricity.

Ministry of Energy and CER **Ongoing**

2.3 The role of wave and tidal in the future energy mix

Marine energy has the potential to support different industries, communities, regions and countries in various ways. Wave and tidal energy capture may be used to provide electricity but also for fluid power (pumping capacity), desalination of water, heat generation, etc.

There are secondary benefits associated with the incorporation of wave and tidal power in the energy mix related to energy diversity, energy security and resilience to increasing fuel costs. There are also indirect benefits in terms of employment and wealth creation opportunities. Along with these benefits there are the possible impacts shared with traditional energy systems, as well as new impacts for example on sea and coastal users and on customers who are served by currently cheaper, but less sustainable, forms of energy.

Due to this mixture of influences that can arise from the adoption of marine energy, it is helpful to plan such developments at a strategic and well as a project specific level. The overall objective of such planning activities is to ensure that developments take place in the best place, at the best time and in the best way, to maximise benefits and reduce negative outcomes. Within such a framework, wave and tidal energy have a greater capacity to contribute to the overall energy mix.

2.4 The current situation – the status of wave and tidal power in Chile

Wave and tidal power technologies are developing rapidly but generally remain at a pre-commercial stage of development. Most technologies are expected to become cost and functionally competitive with other forms of renewables by the mid-2020s.

The fact that much of the marine renewable energy sector is not yet commercialised means that Chile has a chance to play an active role in the development of these technologies and this industry – something that would be harder to achieve for example in wind or solar, where the market is already consolidated.

In Europe and elsewhere, significant subsidies have been provided to support wave and tidal power development – in the UK for example, electricity produced by marine energy may qualify for market-pull support equivalent to approximately five times the market price. Countries which have been willing to invest in such subsidies have taken an early lead in the emerging marine energy industry, with a focus on developing devices for utility scale electricity generation.

Case study 2-A: IEA marine energy publication (International)

The International Energy Agency publishes an annual review on the status of marine energy globally. This provides one of the best and most accessible overviews of global progress for the wave and tidal sectors. This global review can however lack detail at the national level, so care should be exercised in drawing conclusions solely from that publication.

Recommendation 2-B: Publication of annual industry status update

It may be useful to publish a periodic (annual) update on progress related to the marine energy sector. Chile may wish to consider nominating a representative on the International Energy Association (IEA) marine energy committee and updating the IEA for their annual reporting.

Ministry of Energy **Ongoing**

Chile was a pioneer in electricity market deregulation and has a system which operates on a lowest cost model with separation of the functions of generation, transmission and distribution. Despite this non-interventionist approach, market prices remain relatively high and government incentives for renewable power generation do exist. The Chilean Government has an official target of 10% “non-conventional” renewable energy[8] by 2024 and recently increased this (with an as-yet aspirational target) to 20% by 2025. The obligations associated with these targets are however technology neutral and price capped at a relatively low level, so do not provide obvious support to pre-commercial technologies such as wave and tidal power.

Marine renewable energy has nonetheless enjoyed an increasingly high profile in Chile as of late. In the last year alone, the Chilean Government has announced 27m USD of support for marine energy over the coming years, to be delivered through a marine energy centre of excellence (13m USD) and wave and tidal pilot projects (9m USD and 5m USD respectively). The government has also funded a number of related marine energy studies targeted at establishing the current status of the regulatory framework and the process for consenting projects, environmental impact assessment and infrastructure capacity.

[8] Excludes hydroelectric projects over 20MW capacity.

2.5 The scale and availability of wave and tidal energy in Chile

The potential for developing marine energy in Chile is well known and has been covered in other studies (E&A/UoE, 2012), (Garrad Hassan, 2009). It could be argued that Chile is the best place in the world for wave energy, with over 4,000km of coast exposed to consistent and high energy Pacific swells, and centres of electricity demand on or near this coast. Chile´s tidal energy resources are also significant – particularly in the Strait of Magellan and the Chacao Channel but also in many smaller sites throughout the south of Chile. As shown in Figure 16 below, wave energy is Chile´s largest renewable resource and whilst much of this energy is located off the coast of Patagonia (far from energy demand), the aforementioned studies have shown that wave activity is high enough for power generation on all of Chile´s exposed Pacific coastline.

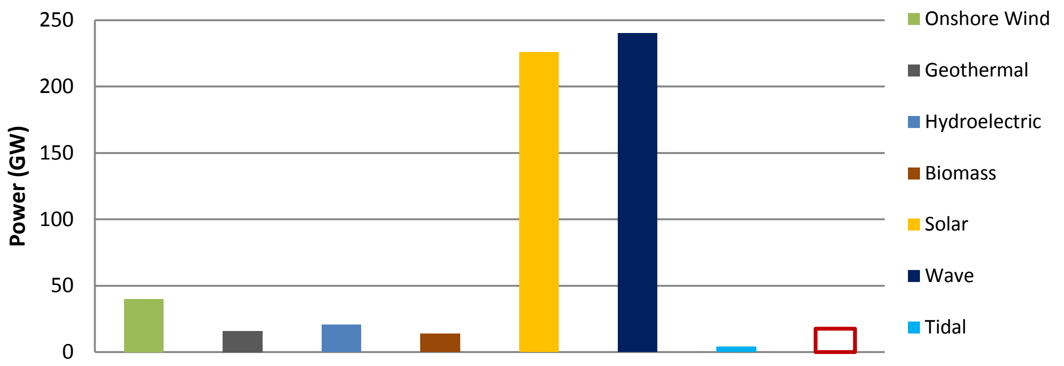

Figure 16: Chilean total (raw) renewable energy resources and current generating capacity (including non-renewables) Sources: Renewable Energy Centre; Baird & Associates

Note: This report considers wave and tidal power - other marine energy sources such as offshore wind or ocean thermal gradient are not considered.

In the north of Chile in particular, the high consistency of wave energy can be an important advantage for balancing power requirements, as can the fact that any fluctuations in available wave energy are independent of changes in solar radiation or thermal wind effects.

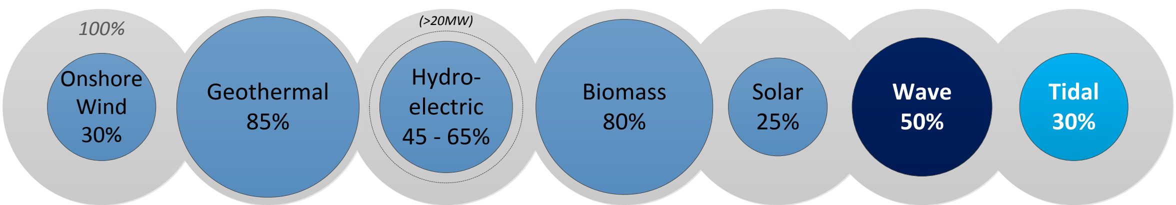

Figure 17: Typical renewable energy capacity factors in Chile

Figure 17 compares approximate capacity factors for Chilean wave and tidal plants with typical values for other forms of renewable generation (Ministry of Energy, 2012). Capacity factors for wave power projects in Chile will be higher than in many other locations worldwide (Monárdez, et al., 2008).The high consistency of the wave regime will however make marine operations more challenging.

Tidal projects tend to have lower capacity factors as a result of the gaps in generation associated with the reversal of flow direction but these fluctuations are highly predictable and, as with the variations in wave energy levels, are out of phase with solar and wind effects. Chile´s main tidal sites also suffer from less floating debris (ice/trees) and wave action than other sites internationally such as the Bay of Fundy in Canada or the Pentland Firth in Scotland. This Chilean advantage makes design, installation and operation of equipment more straightforward and lower risk – thereby lowering costs.

The following chapters of this report seek to evaluate, based on the current state of international marine energy development and Chilean policy, what measures could be included in the Chilean Government´s marine energy strategy and adopted by other organisations, to encourage marine energy to commercialise sooner rather than later, bringing jobs and investment and ultimately a new Chilean industry.

Recommendation 2-C: Definition of future role of wave and tidal energy in Chile

There are many benefits from identifying clear but realistic roles for wave and tidal energy within Chile's energy mix. Each form of energy will have a very different role to play. Tidal energy is limited in overall scale and distribution, but as a more developed technology will have an important role to play in demonstrating the viability of marine energy projects in Chile.

Wave energy is more widespread and the scale of potential is perhaps a hundred times greater than for tidal. The total potential for wave power to supply electricity to the Chilean grid and to support industry as well as isolated coastal and island communities needs to be better understood.

The **Ministry of Energy** and **CER** are already supporting projects to develop the understanding of Chile´s marine energy resources, and it is hoped that this will continue (see also: Recommendation 2-D below and Recommendation 5-B, page 41).

A fuller understanding of the future roles of wave and tidal energy in Chile would help inform appropriate marine energy strategy (see also: Recommendation 4-P, page 30). The potential for Chile to act as a gateway for technology development and deployment within Latin America and the Asia/Pacific market is also worth including within this work.

Ministry of Energy / CER **Ongoing**

Recommendation 2-D: Characterisation of tidal resource

Wave resources have already been modelled and mapped for Chile at a level that provides sufficient detail for near term planning purposes (see regional maps), but the distribution and scale of tidal stream resources in Chile needs to be better understood.

Ministry of Energy / CER **Short term**

3 The Chilean Ministry of Energy´s Marine Energy Strategy

The Chilean Government has published a National Energy Strategy for the period 2012-2030 (Chilean Government, 2012). The stated main pillars of this strategy are to increase the contribution from non-conventional renewables and to drive forward energy efficiency. The Chilean Ministry of Energy now aims to produce individual strategies for each strategically important form of Non-Conventional Renewable Energy (NCRE, see definition in glossary). In June 2013 the Ministry of Energy published a green paper on its draft marine energy strategy, with the following vision statement:

"The Chilean Government recognises the importance of developing renewable energy sources from Chile´s extensive marine resource in order to improve security of supply and mitigate climate change effects whilst contributing to the economic and industrial development of the nation.

To guarantee the maximum economic benefits associated with the use of the country´s marine energy resources, the Chilean Government wishes to establish a "Development Strategy for Marine Renewable Energy" which will allow the country to support the growth of the sector and take an active role in the development of marine energy in Chile´s territorial waters".

(Chilean Ministry of Energy, 2013)

It is worth noting that a 2012 marine energy development study by Errázuriz & Associates and the University of Edinburgh outlined two potential strategies for Chile to pursue:

- *A **development** strategy whereby the country would provide support to the sector in order to take an active role in the development of marine energy technologies and reap the associated economic benefits.*
- *A **deployment** strategy whereby the country would wait for technology to be developed abroad before purchasing and deploying the devices to take advantage of the benefits associated with exploiting the country´s attractive resources* (E&A/UoE, 2012).

It is significant that the Ministry of Energy has explicitly stated its preference for pursuing a development strategy, based on four strategic pillars shown below:

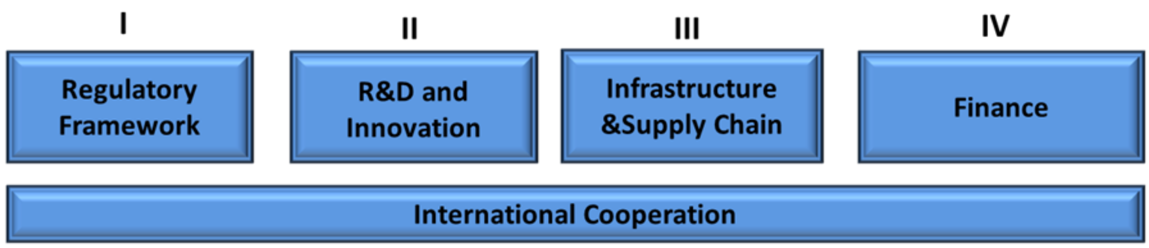

Figure 18: Strategic pillars of the Chilean Government´s draft marine energy strategy

The first strategic pillar is concerned with the development of a robust regulatory framework for marine energy projects and clarification of the process of obtaining maritime concessions for marine energy projects in Chile. Analysis of the environmental and social impacts of marine energy projects is included, with the aim of developing guidelines for project developers and confirming that the current system responds to the marine energy sector´s needs. Cooperation between the government agencies with responsibilities in this field is also to be encouraged.

The second strategic pillar focuses on innovation and basic (but mainly applied) research as well as the development of services and expert professionals. The aim is to consolidate Chilean research capacities and strengthen international links – the creation of the planned marine energy International Centre of Excellence is a key part of this strategy.

The technological advances associated with research, development and innovation activity are highlighted as essential for the emergence of a viable marine energy industry and amongst the important focus areas the following are identified:

- Technology cost reduction and adaptation for Chilean conditions
- Site-specific resource assessment and environmental impact assessment
- Development of systems for isolated communities
- Synergies with other industries, for example desalination and water pumping for the mining industry or off-grid energy systems for communities and salmon farms

The third strategic pillar considers infrastructure (including electricity grid) and supply chain. The Ministry of Energy plans to identify sites with existing infrastructure or the potential to develop capacity which could support the marine energy industry, with the aim of generating a medium- to long-term development plan for those areas with high marine energy potential. Industry requirements in terms of electrical grid capacity and operations and maintenance bases are also to be considered, as is the strengthening of industrial partnerships in the sector.

The fourth strategic pillar seeks to deliver instruments which foster and promote investment in marine energy, through technology transfer and the development of local industry. These instruments span the other strategic pillars and are focused on specific aspects which have been identified as barriers to the entry of marine energy projects. Two funds for the first marine energy Pilot Projects in Chile are to be included. In acknowledgement of the challenges in financing marine energy projects, the investigation of future support measures is also to be considered. Finally improved communication with local banks is put forward as a way of mitigating the perception of the industry´s risk to financiers.

Lastly, the Ministry of Energy has outlined an axis of international collaboration, encompassing recent cooperation agreements signed or in development with, for example, Massachusetts, the UK, Russia and South Korea, as well as various other collaboration projects and specific support measures within each of the four areas of activity.

The following chapter of this report deals with each of these areas in turn, reviewing current policy and progress to date, before developing specific recommendations based on UK and international experience and – crucially – also based on the results of the extensive consultation and local research carried out by the project team.

The Ministry of Energy plans to publish the first version of its marine energy strategy during 2014. It is anticipated that this will be updated periodically. To date the Chilean Government´s marine energy strategy has been developed by the Renewable Energy Division of the Chilean Ministry of Energy, through consultation and coordination with other ministerial departments and non-governmental organisations. This report develops recommendations for inclusion in that strategy but also includes suggestions for the wider marine energy sector. Some of these proposals would require action by central government or industrial or academic organisations and so may not be appropriate for direct inclusion in the Ministry of Energy´s strategy (see also Recommendation 4-P, page 30).

4 Regulatory framework

4.1 Introduction

The first pillar of the Ministry of Energy´s marine energy strategy concerns the regulatory framework.

It is important to make the distinction between two key areas of the regulatory framework regarding marine energy:

1. **Legal or commercial rights to use the sea/seabed.** In Chile at present these rights are administered by a system of maritime concessions controlled by the Subsecretary of the Naval Armed Forces (SUBSECMAR), although there are plans to transfer this power to the Ministry of National Assets, which currently administers onshore concessions.

   Note: in the UK this has generally been managed by a system of commercial leases administered by The Crown Estate, see Case study 4-B*, page 18.*

2. The remaining **permits and licences** required to develop and work on the site, including planning permission, environmental impact assessments (EIAs), navigational permits, grid connection concessions, etc.

Other aspects of marine energy that may require regulatory influence and control include:

- Marine planning
- Energy generation tariffs (see finance chapter)
- Electrical generation standards (see grid chapter)
- Health and safety of workers at sea and emergency response provision
- Maritime marking and navigation (see infrastructure and supply chain chapter)

This chapter focuses on the development of the Chilean regulatory framework as regards maritime concession, permits/licences, marine planning and health and safety.

4.2 Current policy

The key points of the Ministry of Energy´s Marine Energy Green Paper (Chilean Ministry of Energy, 2013) and Marine Energy Strategy include:

- A clear regulatory framework is required which avoids putting barriers in the way of marine energy development. The rules for obtaining maritime concessions need to be clarified for marine energy projects.
- A working group is to be established by the Ministry of Energy with the Sub secretary of the Armed Forces, who currently administer maritime concessions.
- The planned transfer of control of maritime concessions from the Sub-secretary of the Armed Forces (Ministry of Defence) to the Ministry of National Assets is a regulatory change which the Ministry of Energy believes should simplify the process and reduce the time associated with securing these. *Note: As outlined in a recent study by Philippi et al.* (Philippi Abogados, 2012)*, this change is part of a wider piece of legislation governing the administration of the coast and maritime concessions, which could include reforms such as:*
    - *Allowing two or more concessions to be granted for the same area (often difficult or impossible at present - see discussion and Table 3 below);*

  - *Reducing the maximum time a concession can be held from 50 to 30 years - which could free up areas for development.*
  - *Increasing the regulation of appeals to concession applications, so that the grounds for appeal are evaluated before applications are halted.*

- Regulations and procedures for the identification, designation and protection of areas with high potential for marine energy projects are to be evaluated.
- An evaluation of the environmental and social impacts of marine energy projects is required, and to this end the Ministry of Energy is working with the Environmental Evaluation Service in the development of an environmental assessment guide for marine energy projects.
- The roles of the institutions involved in the development of marine energy are to be clarified and mechanisms of cross-ministerial coordination are to be established between the Ministries of National Assets; Environment; Economy; Public Works amongst others.
- The Ministry of Energy and its regional ministerial secretaries are to participate in the National and Regional Coastline Commissions for Coastline Usage.

Case study 4-A: Regulatory framework (Scotland)

In Scotland changes have been made to planning and licensing regime over the past decade in order to deal with new uses of the marine environment. The most important developments for the marine energy sector include:

- Establishment of a 'one-stop shop' for marine licensing (a single point of contact within the government for all licences and permits) and associated streamlining of the consents and licences required for projects in the marine environment.
- Development of bespoke industry guidance and adaptive management policies for marine energy.
- Strategic, nationally-coordinated data gathering and environmental monitoring.
- A Strategic Environmental Assessment (SEA) for marine renewables which identified areas of the country with lesser or greater potential for significant environmental impacts.
- Marine planning, in particular the identification and designation of specific areas as priority development zones for marine energy.
- Commercial rights (leases) have been awarded to marine energy project developers by The Crown Estate prior to the award of permits and concessions (see case study below), giving developers more security before they begin the permitting process.

Although a lot of effort has been made in Scotland specifically to adjust the regulatory framework for marine energy and significant progress has been made, it is important to learn from rather than copy existing regulatory provisions (either internationally or nationally from other sectors). In many cases existing regulatory controls are too complex and precautionary compared to the level of risk involved. By contrast the levels of control applied to safety are often less than appropriate. Chile has a chance to set new and appropriate standards for marine energy that could become a model for other countries if they strike the right balance between control and facilitation. See also Recommendation 4-O, page 28.

Recommendation 4-A: Development of the regulatory framework (implementation of proposed improvements)

It would be beneficial if the proposed improvements to the regulatory framework could be implemented in the short term. The **Chilean Government** may also wish to consider what additional improvements could be made, based on lessons learned from the marine energy sector in other countries and from other sectors in Chile. Some more detailed suggestions are provided below.

Chilean Government **Short term**

4.3 Leases/concessions

In Chile, maritime concessions (or leases) are currently administered by the Subsecretary of the Navy (*Subsecretaría para las Fuerzas Armadas,* SUBSECMAR). Developers are required to apply for separate maritime concessions covering:

- **Water portion** *(porción de agua)* – water column and surface
- **Seabed** *(fondo de mar)*
- **Sea beach** *(playa del mar)* – area between high and low water
- **Beach terrain** *(terreno de playa)* - an 80m wide strip of land inshore of the beach, considered a national (state) asset under most circumstances

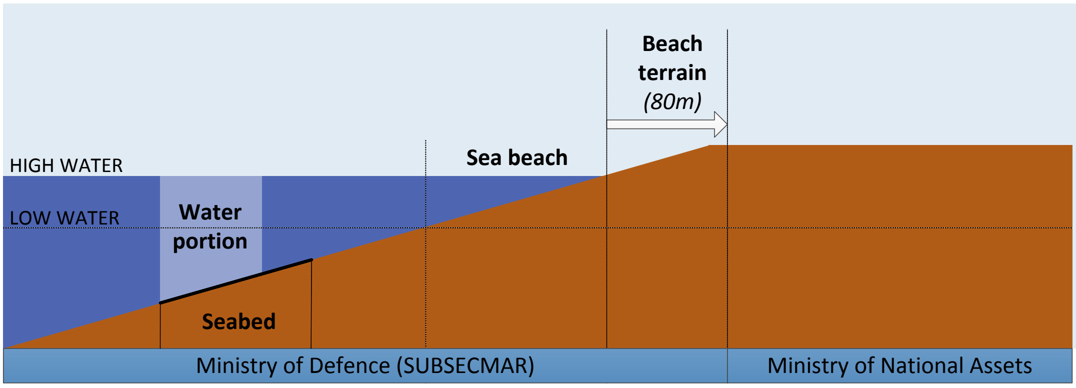

Figure 19: Types of maritime concession in Chile

As has been highlighted in the 2012 Edinburgh University/Errazuriz study, while the Chilean regulatory framework is robust, there is a lack of clarity around the process of gaining permission to develop marine energy sites which has the capacity to hinder development. Some Chilean technology developers have however already installed and tested devices using the temporary maritime concessions which are available (*Concesión Maritima Temporal*).

Whilst the proposal to transfer the responsibility for maritime concessions from SUBSECMAR to the Ministry of National Assets has the potential to simplify the system, this change may take some years, creating some uncertainty in the meantime for the first projects developed. Establishing clear criteria for the evaluation of marine energy projects in the short term would avoid discretionary decisions as a result of this and the "lack of technical capacity" predicted by (Philippi Abogados, 2012) at the Ministry of National Assets following this change. The training of key staff in this regard proposed by (E&A/UoE, 2012) would also reduce this risk.

A separate challenge is to avoid concession "grabs" by speculators – a problem which has been seen to some extent in Chile´s solar and wind industries, where concessions could have been more tightly controlled (for example with incentives and penalties) to ensure progress against the stated timeframes and to limit the time that concessions can be held if they are not developed.

The study carried out by Philippi et al. considered marine energy developments of around 100MW size and concluded that the process of securing a maritime concession for such projects - in which multiple authorities are involved - was "slow, complex and uncertain" and could take at least one to two years to complete (Philippi Abogados, 2012). Further consideration is required for the projects of less than 100MW that will be installed first in Chile.

Another problem highlighted in this study was the potential for conflicts with other sea users. In general, only one type of concession may be granted for a given area. Table 3 gives some examples of cases where the maritime concessions required for marine energy projects could be combined with other types of concession.

Table 3: Compatibility of some different Chilean concessions

Type of concession	**Compatibility with maritime concession such as for a marine energy project**
Fishing and aquaculture	Permissible with consent of existing concession holder.
Areas of handling and exploitation of benthic resources (*Áreas de manejo y explotación de recursos bentónicos, AMERB*)	
Indigenous community coastal zones (*Espacio costero marino de los pueblos originarios, ECMPO*)	
Port works	Permissible, dependent on the limitations defined in the concession.
Maritime traffic	Permissible, works must be appropriately notified/marked.
Tourist areas	Permissible in some cases.
<u>Protected Areas</u>	<u>Permissible?</u>
- National parks	No
- National reserves	Yes
- Virgin zone reserves	No
- National monuments	Yes
- Nature sanctuaries	Yes
- Parks and marine reserves	No
- Coastal marine protected areas	Yes
- Priority sites for biodiversity conservation	Yes
- Ramsar convention sites	Yes

The possibility of the Chilean Government implementing special consents for early stage marine energy projects has been considered and would support the industry´s development. This could take the form of the exploration/exploitation consents available for mining activities (managed by the Ministry of Mining) or geothermal energy projects, managed by the Ministry of Energy.

Recommendation 4-B: Development of clear rules for marine energy concessions; reduction of uncertainty around transfer of powers from SUBSECMAR (Ministry of Defence) to the Ministry of National Assets

It would be beneficial for the rules concerning marine energy projects (including special consents for early-stage projects and projects of less than 100MW size) to be clarified in the short term, in order to reduce the uncertainty associated with these projects and with the potential transfer of responsibility for marine concessions from **SUBSECMAR** (**Ministry of Defence**) to the **Ministry of National Assets**.

Chilean Government **Urgent**

Recommendation 4-C: Marine energy consents training for key staff

As proposed by Errazuriz and Associates (E&A/UoE, 2012), the responsible agency for marine concessions may wish to consider training key staff in the evaluation of marine energy projects, to transfer industry experience and lessons learned from developments internationally.

The responsible agency in 2013 was **SUBSECMAR** (Ministry of Defence) but this may soon change to the **Ministry of National Assets** under the proposed legislative change mentioned in Recommendation 4-B.

Chilean Government **Short term**

Case study 4-B: Leasing (UK)

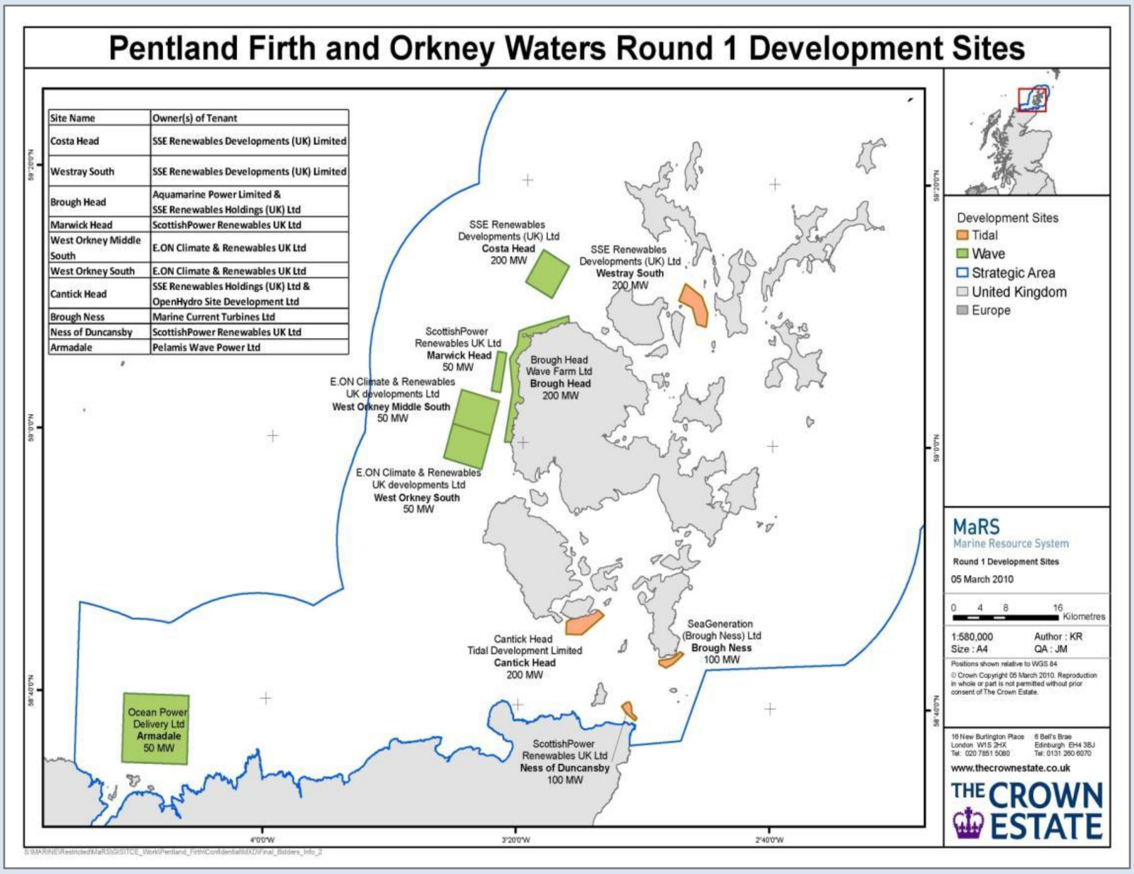

Figure 20: Pentland Firth and Orkney Waters Leasing Round, UK

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Case study 4 B: Leasing (UK) - continued

While Scotland has made strenuous efforts to streamline the process of securing commercial rights to the seabed for marine energy developers, this has been beset with problems from which many lessons can be learned. One of the mechanisms adopted in the UK to accelerate the growth of its marine energy industry was the introduction in 2009 of commercial seabed leases, giving marine energy technology and project developers medium-term security over future leasing options for areas of the seabed. This process was managed by an organisation known as The Crown Estate which owns and manages the UK territorial seabed. This organisation has the right to issue leases for commercial fees to those who wish to make use of the seabed. It is somewhat removed from normal UK governance structures and has a considerable degree of autonomy to act independently. In 2009 following calls from the Scottish Government for an acceleration of marine energy development, The Crown Estate unilaterally decided to hold a commercial leasing round for marine energy in an area defined as the Pentland Firth and Orkney Waters Strategic Area (see map above).

The subsequent lease application process attracted some 41 initial applications, of which 15 were invited to a final round of submissions and negotiations. Finally, seven organisations signed agreements with The Crown Estate for lease options covering 10 individual project proposals. The lease options initially agreed amounted to around 1200MW of installed capacity. Due to the late withdrawal of a candidate developer from a prime tidal site, a further mini leasing round was held for the Inner Sound within the Pentland Firth. This resulted in a 400MW lease option being awarded, giving a total of eight developers, 11 projects and 1600MW of capacity. The successful applicants included a number of UK electric utility companies and technology companies. Some of the key lessons learned from this process are presented below and in the recommendations following this case study.

- Where different companies may end up competing for the same sea space, and other factors associated with the application are acceptable, negotiation should take place to investigate win:win solutions which will allow both applicants to proceed. Applications for small scale demonstration projects as part of the larger leasing process should be encouraged but time limited.
- The award of leases/lease options should be linked to an agreed development schedule to avoid speculation. If this schedule slips then appropriate sanctions are required – this could mean annulling the lease of for example reducing the installed capacity of the lease award by a percentage for every period (e.g. year) of delay. Other key performance factors should also be defined and associated with rewards or sanctions. These may include project safety, level of local content, pattern of energy supply, cost of energy, etc.
- The scale of any lease awards needs to reflect the status of the sectors, particularly with regards to technology readiness and the demonstrable experience of the applicants. Projects of up to 10MW are likely to provide a prudent first step – no projects of this scale have yet been deployed.
- Although one of the stated aims of the leasing process was to avoid a premature "grab" for seabed areas, the eventual approach taken has failed to achieve this. Large areas have been allocated to a few companies, and expansive buffer zones have been created around existing lease option areas which have yet to be developed.

Holding secure use rights of the seabed has however enabled the successful technology developers to adopt a twin track approach of developing their technology and seeking all the necessary consents and permits required, so that they have sites available for commercial use by the time their technology has matured. The publicity around this commercial leasing round has also clearly helped put the UK marine energy industry in the lead internationally.

Recommendation 4-D: Consultation to support the development of a leasing process

It is best to coordinate any strategic release of sea/seabed area options for marine energy developments with all relevant departments of national, regional and local government. It would be beneficial to initiate a consultation process which includes local people and existing sea user groups to support the development of a seabed leasing process for marine energy projects. The proposed marine atlas (Recommendation 4-N, page 27) could support this.

Chilean Government **Short term**

Recommendation 4-E: Leasing of priority development zones for marine energy

The Chilean Government may wish to consider selecting and allocating priority development zones for early stage marine energy deployments. Whilst the current system of maritime concessions will be adequate for some developments, a government-backed initiative to identify and lease the best sites could accelerate this.

The creation of such a seabed leasing process would need to be matched to the envisaged levels of deployment. It may for example be appropriate to establish a leasing process for projects of up to 10MW in the medium term, and a separate leasing process for larger projects in the longer term. These could be linked so that initial demonstration projects could be expanded into full commercial sites.

Lease terms may be used by governments (or leasing organisations) to direct development towards appropriate areas, and clustering of projects to maximise use of resources could be considered.

Public and cross-departmental consultation and coordination can support the development of a robust leasing process, which ideally should be as transparent as possible.

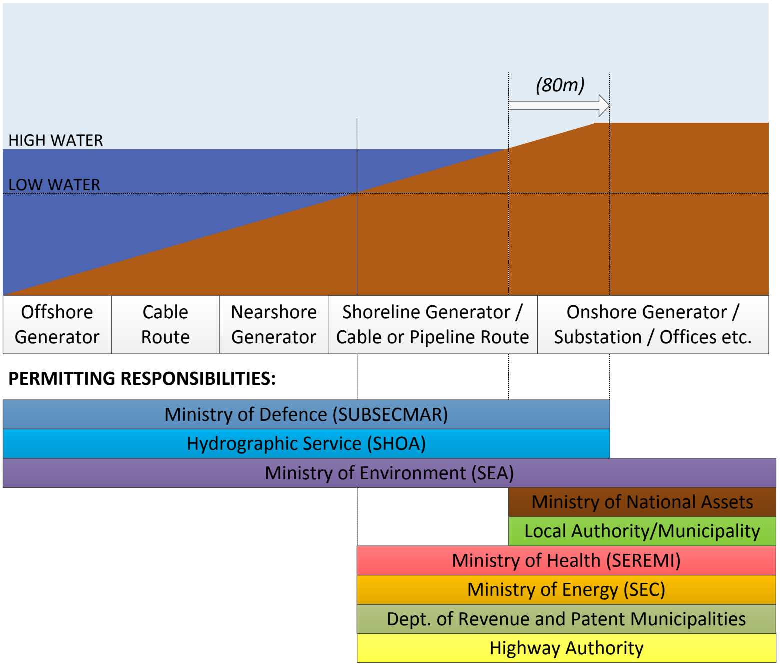
It can be beneficial to allow negotiation between companies competing for the same areas of seabed, but safeguards and incentives are required to prevent speculation and foster successful projects.

Note: see also Recommendation 4-L in marine planning section, page 26.

Chilean Government **Medium term**

4.4 Permits and licences

Permits and licenses provide a framework for establishing how a project should be implemented in a particular place. They consider the type of works to be undertaken, the site specific legislation that may apply, the possible impacts that may arise, means of mitigating these and maximising positive influences, etc. This contrasts with the lease or concession which provides right of access to a particular area of sea and/or seabed. Figure 21 presents some of the main areas of responsibility and permits that may be required to implement a marine energy project in Chile.



MAIN PERMITTING REQUIREMENTS

Approximate Costs and Timescales

Permit	Application Processing Time (days)	Application Fee (CLP)
Maritime Concessions	1 to 2 years	15,000 to 20,000
Navigational Permits	varies	varies
Environmental Statement (or)	varies	varies
Environmental Impact Assessment (EIA)	varies	varies
Permit to rent or buy fiscal real estate	varies	varies
Concession for heavy use of fiscal real estate	varies	varies
Permit No. 2. Building Permit	30	5,000 to 15,000
3. Approval of Preliminary Design.	15	<100
4. Certificate of Prior Information	15	<100
5. Final Acceptance of Works	7	<100
6. Municipal Licence	5	<100
7. Oversize Road Use Permit	5	<100
8. Overweight Road Use Permit	5	1,000 to 5,000
21. Sanitation Report	30	5,000 to 15,000
22. Solid/Industrial Waste Disposal Permit	60	<100
31. Temporary Solid Waste Storage Permit	90	5,000 to 15,000
23. Industrial/Warehouse Qualification	60	5,000 to 15,000
24. Industrial Waste Permit (PAS 91)	unknown	1,000 to 15,000
26. Industrial Waste Permit (PAS 93)	unknown	5,000 to 15,000
41. Provisional Electrical Concession	> 120	5,000 to 15,000
42. Definitive Electrical Concession	138 to 290	Up to 50,000
art. 138 Sewage Permit	varies	varies
art. 139 Industrial or Mining Waste Permit	varies	varies

Only projects of capacity >3MW require an EIA to be submitted for judgement (*Resolución de Calificación Ambiental*)

These Ministry of Health permits are processed through SEIA

Note: Numbers refer to Chilean Government permit register

Figure 21: Potential Chilean permitting requirements for marine energy projects (2012)
Note: costs and timescales can vary greatly depending on project type

The permitting requirements shown above are based on Aquatera´s own analysis and are not necessarily definitive. Whilst there are a large number of organisations and permits presented, it should be noted that many of the permitting requirements shown are relatively straightforward and low-cost. Securing the necessary permits for a marine energy project in Chile is unlikely to be more costly than in other countries such as the UK.

Recommendation 4-F: Production of a licencing manual for marine energy projects

It would be beneficial to produce a licencing manual for marine energy project developers which outlines all of the required steps and responsible agencies for licencing marine energy projects. This could complement the recent marine energy regulatory study (Philippi Abogados, 2012) but also include details on the requirements for projects of less than 100MW size as well as the various other permits required (some of which are shown in Figure 21). The guide for environmental impact assessment of marine energy projects which is currently being developed by the Ministry of Environment would also support this. Such a licencing manual could be similar to the document which the Renewable Energy Centre (CER) has already produced for hydroelectric projects or to Scotland´s Draft Marine Renewables Licencing Manual (The Scottish Government, 2012).

Renewable Energy Centre (CER) **Short term**

Recommendation 4-G: Sharing of information gathered for licence approvals

Where possible it can be beneficial if information and particularly environmental data submitted by project developers is made publicly available or shared between developers. Regulators can also choose to support early stage project developers to gather data in a collaborative manner.

Chilean Government **Short term**

4.4.1 Environmental Impact Assessment (EIA)

It should be noted that projects under 3MW may not be required to be submitted for evaluation by the environmental impact assessment service (*Servicio Evaluación Ambiental, SEA*). Of those projects which do need to be evaluated by the SEA, not all will require a detailed environmental impact assessment – in some cases the more straightforward environmental statement is sufficient. The Ministry of the Environment plans to produce an EIA guide for marine energy projects.

Case study 4-C: Survey, deploy and monitor policy (Scotland)

The Scottish Government has sought to manage the environmental risks of marine energy projects without placing unnecessary restrictions on developers. A Survey, Deploy and Monitor Policy (Scottish Government, 2012) was adopted to provide an efficient risk-based “adaptive management” approach for evaluating the potential environmental impacts of wave and tidal energy developments, based on:

- Environmental sensitivity - whether the site is near or in a designated environmental site
- Scale of development - number of devices or total installed capacity
- Device (or Technology) risk classification, based on factors such as noise generation, pollution risk, entanglement/collision which vary between concepts

This policy started life as “deploy and monitor”, but concerns from ecological advisors led to the survey provision being added. This has proved costly and controversial for the development community who feel that excessive surveying requirements have been imposed on the sector for early stage developments. In particular there has been an expectation of two years of bird and mammals surveying without a clear risk-founded basis for such work. In addition there has been a weak feedback loop between the operational experiences of the past 10 years of marine energy operations and the development of baseline survey and monitoring requirements. This has arisen partly due to development companies failing to monitor enough or publish the results of their observations, and also because of government failing to support monitoring and baseline studies targeted on a risk-basis. Instead funds have been spent gathering wider strategic data which is not directly relevant to the specific potential impacts of wave and tidal energy projects. *(continued over the page)*

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Case study 4 C: Survey, deploy and monitor policy (Scotland) – continued

Scotland´s adaptive management approach has yet to be fully implemented and there is active discussion ongoing about how it can be improved. Likely improvements could include:

- Defining requirements for limited monitoring of all deployments and publishing of results
- More focussed baseline data gathering within site boundaries at particularly active times of year
- Better dissemination of information about experiences to date

There can be a tendency to over-control new activities where uncertainty exists, on the basis of taking a precautionary approach. This presents difficulties for new renewable energy projects, in that more established forms of energy generation are often not subjected to the same controls. It is important that renewable energy projects are required to meet appropriate standards of control based on the real risks of these projects (see 5.4.3). If renewables (and marine energy in particular) are required to meet higher standards than other forms of energy generation then the competitiveness of these generation sources will be compromised. The consequence of this or a failure to formally acknowledge the environmental benefits of renewable energy projects would be to maintain reliance upon carbon intensive forms of power generation.

Recommendation 4-H: Risk-based environmental impact assessment

It would be beneficial to ensure that the scrutiny of Environmental Impact Assessments (EIAs) is informed by risk based assessment which is linked to international marine energy experience. Given the pace of change in the marine energy sector, it may be beneficial to periodically review and update the guide for environmental impact assessment of marine energy projects which the **Ministry of Environment** plans to develop.

The planned marine energy **ICE** may also be able to support the **Ministry of Environment** in this regard (see RD&I section 5.4.3, page 42). As shown in Table 6 and Table 7 (pages 45 and 47), positive local environmental impacts from marine energy projects have already been observed.

The **Ministry of Environment** may also wish to consider reviewing the results of the Survey, Deploy and Monitor policy piloted in Scotland (Scottish Government, 2012) to consider whether aspects of this policy might be applicable to Chile (Case study 4-C, page 22).

Ministry of Environment **Ongoing**

As well as local environmental risks, EIAs should consider the wider environmental and socio-economic benefits of marine energy projects. For example, the main threats to many (if not most) protected species are related to climate change effects. Renewable energy projects are essential to reduce greenhouse gas emissions and combat these effects, but such positive impacts are often ignored during environmental impact assessment.

Case study 4-D: Consideration of the wider impacts of marine energy in EIAs (Scotland)

Although the guidance provided for undertaking Environmental Impact Assessments (EIAs) requires that social and economic factors are taken into account, there has often been insufficient focus on such issues in EIA and permitting processes to date. This is surprising, because the primary driver for government support for marine energy in Scotland is jobs, and particularly jobs for remote and economically fragile areas. Another important consideration which is often overlooked is the positive effect of renewable energy projects on the wider environment. The focus of environmental assessment in Scotland has remained very much on local protection of species and, to a lesser extent, habitats.

Recommendation 4-I: Consideration of the wider impacts of marine renewable energy projects in EIAs

The Ministry of Environment may wish to consider developing criteria to formally take into account wider impacts from marine energy projects in the EIA process. This could include for example the environmental benefits (e.g. habitat creation, pollution reduction and climate change mitigation) and socio-economic advantages which often accompany marine energy projects (see Case study 8-A, page 131 and section 9.4.2, page 138).

Ministry of Environment **Short term**

4.4.2 Streamlining of permitting process

As with the awarding of marine concessions, the fact that marine energy does not generally feature in the permitting legislation could lead to a risk of discretionary decisions. Chile´s permitting system is nonetheless robust, and it is quite possible that marine energy projects would not face significant problems, but the lack of certainty on this issue is another risk factor facing marine energy project developers. The number of different agencies that must be contacted also adds time and cost to project developers´ budgets.

Case study 4-E: Creation of a one-stop-shop and streamlining for marine licensing in Scotland

Marine Scotland was established in 2009 as the directorate of the Scottish Government with responsibility for the integrated management of Scotland's seas. In April 2011, Marine Scotland established its one-stop-shop for marine licencing – a single point of contact for all the permits and licences that marine energy projects require. This approach simplifies the licencing process whilst also enabling coordinated consultation a more holistic assessment of proposed projects. Marine Scotland now aims to provide a decision on all Marine Licence applications within 9 months (where no public inquiry is called).

The Marine (Scotland) Act in 2010 also introduced a simpler licensing system which minimises the number of licences required by consolidating a number of previous systems and processes, therefore cutting bureaucracy and introducing efficiencies. Additionally, special procedures allowing marine and electrical consents to be considered together for renewable energy projects were introduced (UK Government, 2010).

The proposed transfer of responsibility for marine concessions from SUBSECMAR to the Ministry of National Assets has the potential to simplify the process of securing marine concessions (permissions to use the seabed and sea surface) - it is interesting to consider how the process of securing the other permits required to complete a marine energy project might be streamlined.

Recommendation 4-J: Possible streamlining of the regulatory framework for marine energy projects

The **Chilean Government** may wish to review the results of the recent study of the regulatory framework for marine energy projects (Philippi Abogados, 2012) and the environmental impact assessment guide for marine energy projects being developed by the **Ministry of Environment** to consider whether streamlining might be desirable to minimise the number of licences required and regulators involved in the regulatory framework for marine energy projects.

Chilean Government **Medium term**

4.5 Marine planning

Marine planning provides a strategic framework for decisions to be made about the use and protection of marine assets and resources. It can be used to both stimulate and control development, to help optimise economic and social development opportunities and also to help manage and protect biodiversity and cultural heritage interests. The benefits of good strategic marine planning are that it can:

- Provide an excellent baseline understanding of the marine environment;
- Increase awareness of all aspects of the marine environment (physical, ecological, heritage, social, economic, infrastructure and policy environments);
- Act as a stimulus for more focussed studies and investigations;
- Help identify priorities for future development and guide government support mechanisms;
- Help to ensure appropriate management and control of natural and cultural heritage assets.

The national and regional commissions for coastline use (CNUBC and CRUBC) are responsible for marine planning in the different regions of Chile. The Ministry of Energy is represented on these committees, currently with observer status. The 2012 Marine Energy Development report (E&A/UoE, 2012) suggested that voting rights for the Ministry of Energy representatives should be granted and this would seem to be a good way of trying to ensure that marine energy is considered in national and regional marine planning.

Recommendation 4-K: Voting rights for Ministry of Energy representatives on national and regional commissions for coastline use

Ministry of Energy representatives on the national and regional commissions for coastline use (**CNUBC** and **CRUBC**) currently have observer status only. As suggested in the 2012 Marine Energy Development report (E&A/UoE), it would be beneficial if these representatives could be granted voting rights on these committees.

CNUBC / CRUBC **Short term**

Regional coastline use plans are to be developed for each of Chile´s fifteen regions and it is important that marine energy is considered within this process. The results of the proposed cost of energy study (Recommendation 5-B, page 41) could support this process but would be equally valuable as a separate planning tool.

Case study 4-F: Marine planning (Scotland)

The Marine (Scotland) Act in 2010 introduced a new statutory marine planning system to allow better management of the competing demands on marine resources.

Marine spatial planning at the regional level is being trialled through the Pilot Pentland Firth and Orkney Waters (PFOW) Marine Spatial Plan (Scottish Government, 2012). As mentioned in the case studies above, Scotland´s first commercial leases for marine energy projects have been awarded in this area. The pilot plan aims to reconcile the aspirations of the different sea users and to develop a framework for decision making on marine licensing and consent applications.

Scotland´s Marine Atlas (Scottish Government, 2011) is an excellent example of the wider educational benefits that can arise from a focus on marine planning. The breath and detail of information is excellent, and it provides a strong basis of universal understanding upon which more complex discussions on key issues can take place. Despite its many strengths, it also provides some good examples of pitfalls that can be associated with presenting data. For example recreational boating routes are indicated as straight lines between ports when in practice sailing boats and motor boats will take very different courses between such locations based upon sea conditions, seascape features of interest etc. With the expansion of GIS as a tool for analysing spatial relationships, the generation and use of such data sets needs to be carefully evaluated. Trying to avoid an activity which is wrongly characterised in the data may in fact lead to more rather than less impact in reality.

Recommendation 4-L: Identification and designation of priority development zones for marine energy

The national and regional coastline use commissions ("*Comisión Regional de Uso del Borde Costero*", **CRUBC** and "*Comisión Nacional de Uso del Borde Costero*", **CNUBC**) may wish to consider designating priority development zones for marine energy, through consultation with local people and organisations. This work could be coordinated with the **Ministry of Energy** at the national level as part of a wider plan for marine energy and an eventual leasing process (ref. Recommendation 4-D and Recommendation 4-E above).

See also: Recommendation 4-E in leases/concessions section 4.3, page 20.

CRUBC / CNUBC / Ministry of Energy **Short term**

The identification and designation of the most appropriate areas for marine energy projects is most effective when it is supported by strategic data gathering and coordinated environmental research. The following case study presents some relevant initiatives from marine energy development internationally.

Case study 4-G: Strategic data gathering and environmental research (International)

UK and Scottish government institutions have developed programmes of work to inform industry, regulators and stakeholders on the most appropriate locations for wave and tidal power developments. Initiatives include:

- Scoping Paper (Marine Scotland and Crown Estate, 2010) – following on from the Pentland Firth leasing round described previously, this report identified seven new areas for tidal stream or wave power development in Scottish waters. The document provided guidance to planners, regulators and potential developers on the resource, physical characteristics and potential for interactions with other sea users and the environment within these areas.
- Regional Locational Guidance - produced by Marine Scotland in response to comments received on the 2010 scoping paper, this project involved a more detailed analysis of the proposed areas and provided localised information on environmental, technical and socio-economic factors. See: http://www.scotland.gov.uk/Topics/marine/marineenergy/wave/rlg
- Scotland's Marine Atlas - an assessment of the condition of Scotland's seas to inform site selection, project design, environmental assessment, etc. See Case study 4-F above and link below: http://www.scotland.gov.uk/Publications/2011/03/16182005/0
- Marine Scotland Interactive (MSI) is an interactive tool has been designed to assist in the development of the National Marine Plan. The tool allows users to view different types of information and where appropriate, links have been provided to the related parts of Scotland's Marine Atlas where the information is discussed in more detail. See: http://www.scotland.gov.uk/Topics/marine/education/atlas
- A review of the potential impacts of wave and tidal renewable energy developments on Scotland's marine environment has been commissioned by Marine Scotland. See: http://www.scotland.gov.uk/Resource/Doc/295194/0121070.pdf
- In Scotland a Strategic Environmental Assessment (SEA) for marine renewables was carried out to examine the environmental effects of developing Scotland´s renewable energy potential. The results of this assessment were used to inform the preparation and delivery of the Scottish Government's strategy for the development of marine energy as well as guidance for marine energy developers. See: http://www.scotland.gov.uk/Topics/marine/marineenergy/wave/WaveTidalSEA

A number of databases have also been developed which hold information about on-going research, including:

- The NERC Marine Renewable Energy Knowledge Exchange Programme (MREKEP) (https://ke.services.nerc.ac.uk/Marine/Pages/Home.aspx)
- Crown Estate Wave & Tidal Knowledge Network (http://www.waveandtidalknowledgenetwork.com/)
- TETHYS knowledge management system, (http://mhk.pnl.gov/wiki/index.php/Tethys_Home)

The Chilean Ministry of Energy has commissioned the geophysics department of the University of Chile with support from SHOA and DIPRIDA to create a “marine energy explorer” website which presents Chile´s wave and tidal resources in an interactive online platform[9]. It is possible that this could form the basis of an eventual online marine atlas. Alternatively, information from existing agencies such as the Renewable Energy Centre, the Ministry of Environment and the Chilean Navy could be combined to create a Marine Atlas similar to those developed in Scotland and elsewhere.

Recommendation 4-M: Strategic Environmental Assessment (SEA)

The **Ministry of Environment** (possibly with support from the **Ministry of Energy** and **CER**) may wish to consider implementing a national Strategic Environmental Assessment (SEA). The aims of this would be to:

- Assess the environmental impacts of large scale marine energy developments on Chile´s environment at the national level.
- Prioritise environmental risks of marine energy projects in Chile.
- Support the identification of priority development zones and an eventual commercial leasing round.

This would consider the impacts of industrial scale marine energy development and identify the areas where projects can take place with minimum environmental risk. Environmental impacts can be reduced not only by choice of site by also by choice of technology, timing of construction works, selection of supporting infrastructure, etc.

A SEA can examine plausible alternative development scenarios including zero deployment, in order that meaningful comparisons can be made between the impacts of existing activities and potential marine energy deployments. Regional Governments could also consider commissioning their own regional SEAs.

*Note: the results of this work and the proposed cost of energy study could support the **CNUBC/CRUBCs** and **Ministry of Energy** in the identification and designation of priority development zones for marine energy (*Recommendation 4-L *and* Recommendation 4-E*).*

Ministry of Environment / Ministry of Energy **Short term**

Recommendation 4-N: Creation of a national marine atlas and marine plan for Chile

The Chilean **Government** may wish to consider compiling a national marine atlas for Chile which provides information, maps and analysis on current and future levels of activity in Chile´s marine environment. The regional coastline use plans currently in development could form part of this. Such a project could also be linked to existing information held by for example:

- The National and Regional Coastline Use Commissions (CNUBC/CRUBC)
- The Ministry of Energy and the Renewable Energy Centre - e.g. grid, power plants, etc.
- The Chilean Navy (DIRECTEMAR/SHOA/DIPRADA) - e.g. maritime concessions, bathymetry, wave and tidal resources
- The Ministry of National Assets (e.g. land ownership, onshore and coastal concessions)
- The Ministry of Environment (e.g. protected areas, evaluation of environmental risk)
- The marine energy infrastructure study planned by the Ministry of Energy
- The “marine energy explorer” website (University of Chile, 2012)

Measured marine energy resource and seabed bathymetry data (Recommendation 5-A, page 40) and the Strategic Environmental Assessment(s) (SEA) proposed in this report (Recommendation 4-M above) could also support this along with public and inter-departmental consultation. The creation of such an atlas would be a valuable tool for marine planning and stakeholder engagement work.

Chilean Government **Short to medium term**

[9] http://ernc.dgf.uchile.cl/Explorador/Marino/

4.6 Health and safety

Safety at sea has developed through centuries of seagoing activities and experience. New safety management procedures and regulations have been developed for specific industries, such as the oil and gas sector or for container terminals. Installing and operating wave and tidal technologies presents new health and safety challenges which need to be addressed.

Holding station (maintaining position) at a location in a tidal stream is difficult. The forces acting on vessels and equipment are severe and the speed at which any items or people dropped into the sea may drift away can be dangerously fast.

Along exposed coasts, waves can affect the stability of working platforms and create excessive forces on structures. For wave energy projects, vessels may be required to work in waters which are shallower and more exposed to waves and that would normally be avoided. Vessels which break down in these areas may often have little room to drift shoreward before coming aground.

In short, the high energy nature of wave and tidal sites makes them difficult places to work safely.

Despite these added risks associated with marine energy there are few if any examples of bespoke regulatory provisions being made. There have been numerous accidents and near misses in the marine energy sector to date. Risk management and control measures are not yet being applied with sufficient rigour and understanding to make the sector as safe as it should be.

In Chile the Ministry of Labour and Social Security (*Ministerio del Trabajo y Previsión Social*) is responsible for "promoting behaviours that prevent accidents and occupational diseases in the workplace" (Chilean Government, 2010). The Directorate of Labour (*Dirección del Trabajo*) is the subdivision of this ministry which is responsible for overseeing compliance with labour regulations and health and safety at work.

DIRECTEMAR operates coastguard services in Chile and is responsible for overseeing compliance with all national regulations regarding health and security in ports and at sea.

Recommendation 4-O: Creation of health and safety working group for the marine energy sector

The **Directorate of Labour** (part of the **Ministry of Labour and Social Security**) may wish to consider establishing a working group to create a suitable risk management and control framework for Chile´s emerging marine energy sector, possibly in coordination with the **Ministry of Energy** and **CER**. Such a group could comprise practitioners, underwriters, developers and emergency response services and seek to transfer knowledge, experience and lessons learnt from marine energy sector internationally to Chile. This group could also build up a dossier of maritime safety issues in Chile which marine energy project developers planning to operate in Chilean waters could use.

Ministry of Labour and Social Security **Short term**

4.7 Conclusions – regulatory framework

It is critical for the development of a marine energy industry that all policy measures are developed in parallel - a partial or uncoordinated set of policy measures is unlikely to provide the political and industrial drivers required to progress the development of a successful marine energy industry.

For instance, a well-structured consenting and licencing system will not secure the development of a marine energy industry if there is no ready access to grid infrastructure. Similarly, access to grid and a fit-for-purpose consenting system will not be enough for a development strategy to be successful if financial support for pre-commercial projects is not available.

Case study 4-H: Marine energy strategy (Scotland)

A report published in 2004 by the Marine Energy Group (MEG) of Scotland´s Forum for Renewable Energy Development (FREDS) asserted that by 2020, 10% of Scotland's electricity could come from marine renewable sources and highlighted the opportunity for 1,300MW of marine energy capacity to be installed in Scottish waters with the creation of 7,000 jobs and the potential for Scottish-based marine energy companies to become major suppliers of international energy export markets (FREDS/MEG, 2004). This document formed the foundations of the Scottish Government´s developing strategy for marine energy. A roadmap (FREDS/MEG, 2009) and action plan (FREDS/MEG, 2012) have since been developed by the marine energy group as a way of monitoring progress against these ambitions, and updating the specific recommendations.

MEG was an invited group which the Scottish Government has now formed on 3 occasions. Each group has been shaped to best meet the challenges of the time as they were understood. In the early years this group comprised technology inventors and academics, now it needs a wider more representative basis as the issues become more complex and integrated across the supply chain, government and society in general. This group has also had strong links to Scottish Renewables (SR), a trade body that has wide civic, academic and commercial membership. Both MEG and SR have sought to examine the wider picture and deliver broad based solutions appropriate, as far as practical, to all. The establishment of a group of specialist advisors with whom the government can informally explore options has worked well.

Based partly on the findings of the MEG research, the Scottish Government is supporting marine renewable energy sources to contribute significantly towards achieving Scotland's target of generating 100% of the country´s electricity from renewables by 2020.

The fact that the Ministry of Energy aims to establish a development strategy for marine energy is an extremely supportive development, as is the fact that the Ministry of Energy plans to encourage cross-ministerial coordination on marine energy - there are many policy areas where coordinated action from different government ministries will be required to successfully support the marine energy industry.

The Ministry of Energy however, must necessarily define activities in its strategy which are within that organisation´s remit to carry out. This can include identifying barriers to marine energy development and setting up working groups with other ministries to try and combat these (for example with the Ministry of Defence and Ministry of National Assets on maritime concessions), but change required in these areas of government must be implemented by the ministry responsible. Similarly, there are benefits of marine energy in terms of job creation and investment which are central to the case for marine energy, but on paper at least, they are the concern of the Ministry of Economy rather than the Ministry of Energy.

It may be that the formation of an independent group with responsibility for tracking progress on marine energy development and updating strategic recommendations would be beneficial. Such a group could be made up of experts and representatives from different governmental and non-governmental agencies (including industry and academia), similar to the Marine Energy Group in Scotland. If assembled by central government or backed by the right organisations, such a body could be empowered to make independent recommendations and influence policy in a way that would be more difficult to achieve within government.

Whilst the Chilean Government sets and enforces targets for overall renewable energy supply, it generally refrains from setting specific targets for individual types of renewables such as wave or tidal. The identification of achievable targets can help drive the sector forwards, and an independent marine energy strategy group could be well placed to propose such targets (even if they were aspirational) as part of their recommendations.

Recommendation 4-P: Development of a robust marine energy strategy; appointment of independent steering group to review, advise and publish progress

Any strategy in the fast moving area of energy policy will be valid for a limited time only. It is therefore necessary to revisit and update Chile´s marine energy strategy on a regular basis, to include the most up to date information and build on work done previously, such as this roadmap project. It can be helpful to identify responsible organisations and timescales for specific actions to be completed. The **Chilean Government** and particularly the **Ministry of Energy** may wish to consider the formation of an **independent strategy review group** with responsibility for this task.

Ministry of Energy / Independent strategy review group **Ongoing**

Recommendation 4-Q: Creation of a sub-committee for marine energy within the parliamentary energy commissions

It may be desirable to establish marine energy sub-committees within the **Chilean Government´s** parliamentary energy commissions (Senate and Deputy chambers).

Chilean Government **Short term**

Recommendation 4-R: Marine energy projects and technology register

The **Ministry of Energy** already holds a register of the organisations active in marine energy in Chile, and the draft Marine Energy Strategy includes information on many of the marine energy devices in development internationally and nationally. Continuing to update this register with information and data on marine energy technology and project activities would be useful. This could also include certain enabling technologies and infrastructure such as those identified in the planned infrastructure study (i.e. installation vessels or shipyards). **CER** and the planned marine energy **ICE** could also support this.

Ministry of Energy / CER / ICE **Short term**

5 Research, development and innovation (RD&I)

5.1 Introduction

The second pillar of the Ministry of Energy´s Marine Energy Strategy concerns research, development and innovation (RD&I). RD&I is the backbone of any emerging industry and an integral part of progress from the early stages of technology testing to the realisation of an economically viable, commercial scale industry.

Historically, Chile´s growth has been driven by resource export-oriented industries (principally mining and agriculture). According to the OECD, Chile has suffered from "comparatively low investments in research & development, over-emphasis on research as compared to innovation in the funding system" and "shortfalls in the formation of human capital" (OECD, 2009). In recent years however the Chilean government has taken strong action on this front, notably by:

- Creating a National Innovation Council for Competitiveness (*Consejo Nacional de Innovación para la Competitividad*, CNIC), which advises the government on innovation policy and evaluates bodies such as CORFO.
- Introducing a levy on mining to fund strategic RD&I projects.
- Introducing a tax credit for RD&I spending (recently expanded) to encourage the private sector to participate more in these projects.

For marine energy, the most significant recent development has been the announcement that InnovaCORFO and the Ministry of Energy are to invite bids for the creation of a USD marine energy International Centre of Excellence, with 13m USD of grant funding spread over eight years[10]. Through the creation of this centre the Chilean Government aims to consolidate existing research capacities and attract international research groups with relevant knowledge and experience to Chile, creating collaborative networks that produce services and products directly focused on local industry needs.

Secondly, the Chilean Government and the Inter-American Development Bank plan to support the first large scale marine energy pilot projects in Chilean waters. The total support available is understood to be around 14m USD and discussions have been ongoing as to how this will be divided between wave and tidal.

There are also many existing funding lines available for RD&I projects which are not specific to marine energy (see Figure 41 in Finance chapter 7, page 80).

5.2 Current activity

Chile has some of the leading universities and research institutes in Latin America and many are already active in marine energy research, often in partnership with private companies. Examples include:

- Ongoing wave and tidal resource assessment project which led by HydroChile, which also includes an environmental study of the Chacao Channel;
- Work by the naval engineering department of Austral University on low-flow tidal turbines for salmon farming site;

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[10] http://www.corfo.cl/programas-y-concursos/programas/atraccion-de-centros-de-excelencia-internacional-de-id-en-energia-de-los-mares

- Concepción University´s department of Oceanography which is investigating the use of high frequency radars for wave and tidal current measurement;
- Federico Santa Maria University project on the performance of WaveDragon´s overtopping turbine, and other power electronics and power modelling work including the design of power converters for marine energy generators based on permanent magnet generators;
- Online wave and tidal energy resource mapping project *"Explorador de Energía Marina"* (marine energy explorer website) led by the Geophysics Department of the University of Chile with SHOA and DIPRI [11];
- A research project on environmental considerations of marine energy by the University of Magallanes and the Centre for Quaternary Studies, Fuego-Patagonia and Antarctic Centre (*Centro de Estudios del Cuaternario, Fuego-Patagonia y Antártica*, CEQUA).

There are a number of private companies developing early stage wave and tidal technology concepts, including:

- Ausind – recently tested a part-scale demonstrator of their point absorber wave energy offshore, near Valparaiso;
- Blue Power Projects - have carried out concept teests of a wave energy prototype in El Quisco, near the port of San Antonio)
- ETYMOL – have carried out controlled tests of a scale prototype of their wave energy device;
- Maestranza Diesel – have tested various small-scale coastal wave and tidal power prototypes, including a recent deployment in the Chacao Channel;
- Undimotriz Chile – developing a wave energy concept;
- Wilefko – recently tested a small-scale prototype of their wave energy flap at Concón.

Utilities and large industrial companies are also taking an interest in the sector, including Abengoa, Andritz Hydro Hammerfest, DCNS, Endesa, Siemens, Voith, etc. Other members of the supply chain are taking an interest as well (Baird, Birchman, Green Elements, Hatch [previously Proconsa]). Finally there are a number of international research and commercial organisations that have started to develop links with Chile and to become directly involved in the country´s emerging marine energy sector (Aquatera, WAVEC, NNMREC, Edinburgh University, Heriot Watt University and others).

Consultees to this project voiced concern about a lack of collaboration between universities and local companies in Chile, who may be risk-averse and unwilling to invest their own funds in external RD&I. The role of industry in helping shape research lines for universities has the potential to be strengthened as a way of coordinating the needs of industry and RD&I objectives of national researchers. Progress is being made on this front with new initiatives from CORFO (see Figure 41) and especially InnovaCORFO. The planned marine energy International Centre of Excellence is the most obvious example and has the stated objective of bridging the gap between academia and private industry.

The Ministry of Energy´s has confirmed RD&I as a fundamental part of Chile´s long-term strategy, with a key role to play in encouraging the growth of a marine energy industry through basic and applied RD&I, innovation and the development of services and workforce training.

[11] http://ernc.dgf.uchile.cl/Explorador/Marino/

5.3 Funding priorities

The amount and structure of RD&I funding for marine energy projects are important factors to consider. Globally, the pattern of funding to date has been almost exclusively focussed upon support for primary technology inventors and secondary technology development companies who have bought rights (patents) from the inventors. In the UK and many other countries, technology companies have been expected to be responsible for a whole spectrum of activities that are not necessarily related to their core business plans, such as finding and surveying sites, organising grid connections and building political support. The distractions caused by such activities are exacerbated by the small size of many of the technology developers, who may struggle to maintain a focus on technology development.

Increasingly in many technology related industries even the basic manufacturing or assembly of systems is contracted out, so that the core technology company focus mainly on technology design and manufacturing items with key Intellectual Property (IP) associated with them. In the future it seems likely that specialist project development and marine operations companies will become established and the responsibilities for overall delivery of marine energy will be more widely shared. This may also affect some of the funding streams, with more funding going to non-technology activities which are then able to better stimulate the ultimate markets for the devices at the right price points in those various markets. This may lead to an increase in sector enabling funds targeted at areas of research or capacity building which support wider industry development.

Case study 5-A: Sector enabling funds (Oregon, USA)

Oregon has perhaps had the most diversely based funding programme for marine energy. Funds have gone into enabling studies and industry support in addition to direct technology support. It is notable that the Oregon Wave Energy Trust (OWET) is predominantly made up of supply chain service providers. This has perhaps broadened the funding priorities. Such a focus on enabling can make sense - given the lack of a support tariff in the USA and low energy costs, the economic case for technology deployment is less strong than in other parts of the world. In addition Oregon has been more successful in identifying many of the strategic barriers and opportunities that face the wave sector, before major development takes place, than other geographical areas.

Case study 5-B: Sector enabling funds (Scotland, UK)

Enabling funds have also been made available in the Pentland Firth Orkney Waters (PFOW) area by the UK Crown Estate, recycling some of the income taken from lease fees and including additional finance from the Crown Estate, the Scottish Government and specialist government bodies. Whilst a considerable amount of money has been spent, the focus of the studies has often missed the key priorities that could have best "enabled" the specific projects targeted or the sector in general. In some cases, decisions to support studies were made without sufficient consideration of local knowledge/experience or input from broader supply chain. Consequently some key, and relatively simple, questions remain unanswered whilst there is a considerable of amount of expensively gathered information that may prove to have little value to the future of marine energy. It is important therefore that an appropriate foundation of relevant expertise, experience and understanding informs the allocation of any strategic funding programmes if the best outcomes are to be achieved.

The European Union has also provided many different funding mechanisms to support the development of the marine energy industry. Some of these are shown for reference in Case study 5-C, Table 4. It can be seen that alongside technology-focused studies there have been a number of projects aimed at developing supporting capacity and at coordinating the industry in general. See related Recommendation 5-I on research coordination, page 57.

Case study 5-C: European Union (EU) marine energy research funds

The table below provides details of some relevant EU funding initiatives for reference.

Table 4: European Union marine energy research funds

Project	Start	End	EC budget contribution	Description/purpose
Coordinated Action on Ocean Energy (CA-OE)	2004	2007	€ 150,000	Coordinate development of coherent research and development policies within key areas of ocean energy research and development; marketing of research deliverables, revision and implementation of standards related to monitoring performance, safety & design.
EU-OEA Dissemination	2004	-	€ 1,593,000	Disseminate information from the numerous separate research and deployment activities
POWWOW	2005	2008	€ 1,049,646	Co-ordinate the activities in related fields (short-term forecasting of wind power, offshore wind and wave resource prediction; wakes in offshore wind farms). Disseminate knowledge and plan for future.
SEEWEC	2005	2008	€ 2,299,755	To assist in the development of a 2nd generation FO³ wave energy converter through extensive use of the experience from monitoring a 1:3 laboratory rig and a 1st generation 1:1 prototype.
WAVE DRAGON MW	2006	2009	€ 2,431,000	Develop Wave Dragon technology from a steel 20 kW prototype to a full size composite-built 7 MW unit and validate techno-economic feasibility
EquiMar	2007	2013	€ 3,990,024	Develop protocols for the equitable evaluation of marine energy converter
NEREIDA MOWC	2007	2010	€ 831,555	Demonstrate the incorporation of Wells turbine OWC technology in a rubble mound breakwater in Mutriku, in the north coast of Spain
WAVEPLAM	2007	-	€ 526,988	Develop conditions (tools, methods and standards) to speed up introduction of ocean energy into the European renewable energy market
CORES	2008	2011	€ 3,449,587	Development of concepts and components for power-take-off, control, moorings, risers, data acquisition and instrumentation on floating OWC systems.
Pulse Stream 1200	2009	-	€ 8,008,935	Produce a demonstrator pre-production 1.2MW prototype of an innovative tidal power technology
Standpoint	2009	-	€ 5,096,653	Standardisation of Point Absorber Wave Energy Convertors by Demonstration
Surge	2009	-	€ 2,997,000	Project to create a grid-connected wave energy converter
ORECCA	2010	2011	€ 1,599,032	To create a framework for knowledge sharing and to develop a research roadmap for activities in the context of offshore renewable energy
MARINA PLATFORM	2010	2014	€ 8,708,660	Pan-European project dedicated to bringing offshore renewable energy applications closer to the market by creating new infrastructures for offshore wind and ocean energy converters
SOWFIA	2010	2013	€ 1,442,345	Provide recommendations for approval process streamlining and European-wide streamlining of impact assessment processes
Waveport	2010	-	€ 4,591,850	Demonstration & Deployment of a Commercial Scale Wave Energy Converter
Fame	2010	2013	€ 3,400,000	Strategic transnational co-operation project to enable the protection of the Atlantic marine environment.
MARINET	2011	2015	€ 8,999,997	Free-of-charge access to world-class research and development facilities

5.4 Research focus areas

Amongst the potential lines of research that Chile could prioritise, the following have been highlighted by the Ministry of Energy:

- Technology cost reduction and adaptation for Chilean conditions
- Site-specific resource assessment and environmental impact assessment
- Development of systems for isolated communities
- Synergies with other industries for example mining and aquaculture (market niches)

These and some additional potential RD&I focus areas are examined in detail below.

5.4.1 Technology cost reduction and adaptation for Chilean conditions

The Chilean Government´s aim is for Chile to take part in RD&I activities which bring the cost of marine energy down so that wave and tidal power can compete with other types of non-conventional renewable energy in Chile´s competitive electricity market. This can and should include the development and adaptation of existing technology from abroad as well as the development of new Chilean technologies.

As is discussed in the finance chapter of this report, the dynamics of the relationship between cost of energy and value of markets is complex and changing. There may be markets in Chile already where wave or more likely tidal energy could compete on cost with existing energy supply systems. However, pattern of energy supply, reliability and acceptability are all issues that need to be looked at as well as fundamental cost.

For the wider large scale energy markets it is clear that cost certainty as well as cost reduction are likely to be essential requirements. Appropriate adaptation to local conditions will play a large part in contributing to cost reduction, as will local manufacturing. Given that Chile is a major producer of copper and also of some steel, the possibility of subsea cables and devices for the Latin American market being manufactured in Chile is attractive.

A number of potential Chilean research focus areas have been proposed in the draft Marine Energy Strategy and in this report but the challenge remains to define these fully in consultation with local and international RD&I organisations and the wider industry (Recommendation 5-I, page 57).

Key characteristics of Chilean marine energy sites and their impacts are considered in Table 5.

Table 5: Key characteristics of Chilean marine energy sites

Characteristic	Wave Sites	Tidal Sites
Energy resource	High energy and consistency = high capacity factors. Sufficient levels of energy for generation throughout the country, but higher in the south.	Comparable with other sites internationally.
Water depths (bathymetry)	Deep close to shore and steeply sloping – high energy close to shore, but the size of the suitable seabed strip is reduced. Novel mooring and foundation designs required.	Somewhat deeper than many international sites.
Operating conditions	Consistent large, long period waves – will affect fatigue and extreme loading conditions for design. Marine operations to install and maintain devices may be more challenging.	Typical tidal flows but less wave action and floating debris (trees/ice) – makes design and marine operations more straightforward.
Distance to port	Many suitable ports exist. Resource is so extensive however that there are also many excellent sites far (>24hrs @4knots) from ports.	Most significant sites are within a few hours of ports.
Other sea users	Busy near ports; many small fishing communities.	High vessel traffic in Chacao Channel and Magellan Strait.
Environmental	Globally significant species. Protected indigenous areas.	Globally significant species.
Other	Earthquake and tsunami risk (low in the far south of Chile).	Earthquake and tsunami risk (low in the far south of Chile).

These factors will require existing technologies to be adapted, new designs to be developed and novel operating methods and procedures to be adopted.

Case study 5-D: Marine energy cost reduction (UK)

The following areas were identified in the Future Marine Energy Report (Carbon Trust, 2006) as having the most potential for marine energy cost reduction:

- Device components – Research into lowering costs and improving performance of specific components in existing marine energy devices.
- Installation, operation and maintenance – Developing strategies to enable marine energy devices to be installed, operated and maintained at a lower cost.
- Next generation concepts – Developing new device concepts that could significantly lower the costs of marine energy compared with other front runners.

Subsequently, the £3.5m UK Marine Energy Accelerator (MEA) programme was launched to explore cost reduction in marine energy (Carbon Trust, 2011). Focusing on the three areas identified above, this project describes the potential for cost reduction as follows:

> *Energy from wave and tidal energy converters will become more affordable as the number of devices manufactured increases – so-called 'learning by doing'. For energy devices this equates to cost of energy (in p/kWh) dropping by a fixed rate for each doubling of cumulative annual output (in kWh per year). This can be plotted on an experience curve or as a 'learning rate'. Technology innovation can increase the rate of cost reduction – steepening the learning curve – or start the curve at a lower level.*

The report describes how the cost of energy from marine energy devices can be reduced through two distinct, but often overlapping, effects:

- *From reductions in the six cost components identified as the constituent parts of the cost of energy (Figure 23), which reduces capital or O&M spend per kWh of output;*
- *From improvements in device performance, which increase the number of kWh per unit of capital and operating spend. Efficiency improvements increase the output of the device while operating, while reliability improvements increase the time spent generating electricity.*

The cost components of wave and tidal power differ as a result of their distinct operating environments and methods of energy capture, as illustrated in Figure 22.

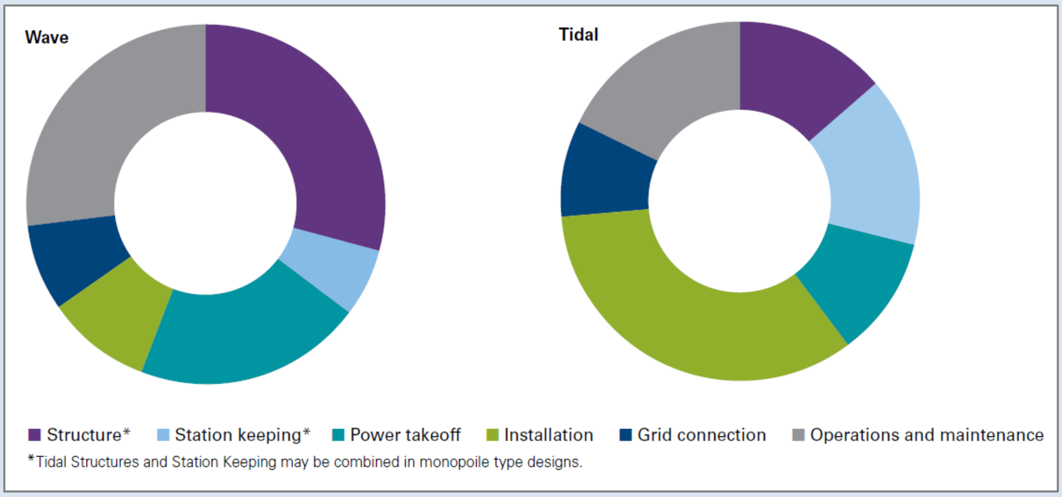

Figure 22: Indicative Levelised Cost of Energy (LCOE) components for wave and tidal energy converters in an early commercial farm (Carbon Trust, 2011)

Note: Coloured segments are capital costs, while the grey segments represent O&M costs and include all other spend including insurance and leases.

Each of the cost components shown in Figure 22 has the potential to be reduced and some cost components have greater cost reduction potential than others – see Figure 23 below.

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Case study 5 D: Marine energy cost reduction (UK) - continued

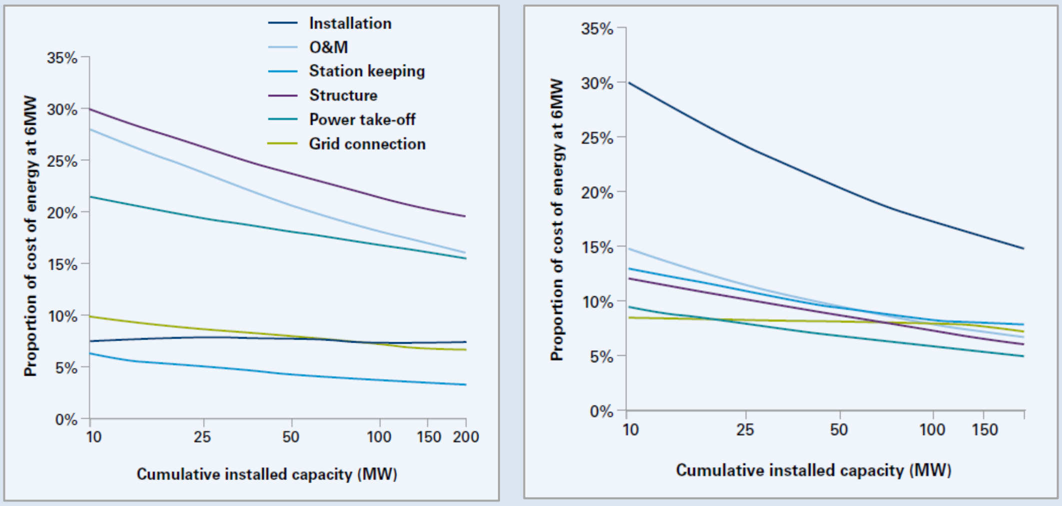


Figure 23: Potential cost reduction curves for wave (left) and tidal power (right) by cost component (Carbon Trust, 2011)

The areas with most potential for cost reduction are often the same areas which require Chile-specific solutions. This is particularly true for wave power, where the nature of the Chilean sites (high energy and consistency; long periods; steep and deep bathymetry) will require designs developed abroad to be changed (devices may be longer/deeper) and new installation and maintenance procedures to be developed.

Figure 23 show potential cost reduction curves for wave and tidal power. For wave it can be seen that installation, operations and maintenance (O&M) and station keeping (i.e. mooring or foundation design) make up the largest components of the cost of energy and have the greatest potential to be reduced. Within tidal, installation costs are a key focus area.

The UK energy technology institute and energy research council are both active in coordinating and supporting research focused on technology cost reduction (ETI/UKERC, 2010) (UKERC, 2012).

Most recently, the Strategic Initiative for Ocean Energy has also investigated the cost reduction opportunities within ocean/marine energy (SI OCEAN, 2013).

It is apparent from the UK case study above that the potential for wave energy cost reduction through RD&I and innovation activity which is targeted at structural, station keeping and O&M cost is significant. These are likely more interesting areas for Chile to focus on than, for example, power take-off systems or grid connection, where the scope for cost reduction is lower and Chile-specific solutions may not be required.

Device mooring is another specific area where RD&I and innovation will be required to adapt marine energy technologies to Chilean conditions. Offshore wave energy projects in Chile will need moorings or foundations which are suitable for more steeply sloping and/or deeper seabeds (see Figure 24) as well as seismic and tsunami risks.

Tidal is a more mature technology than wave, and Chilean tidal sites are similar to others in development internationally, however there are still opportunities to focus RD&I where cost reduction potential is greatest, particularly around installation technology and methods (see Figure 23).

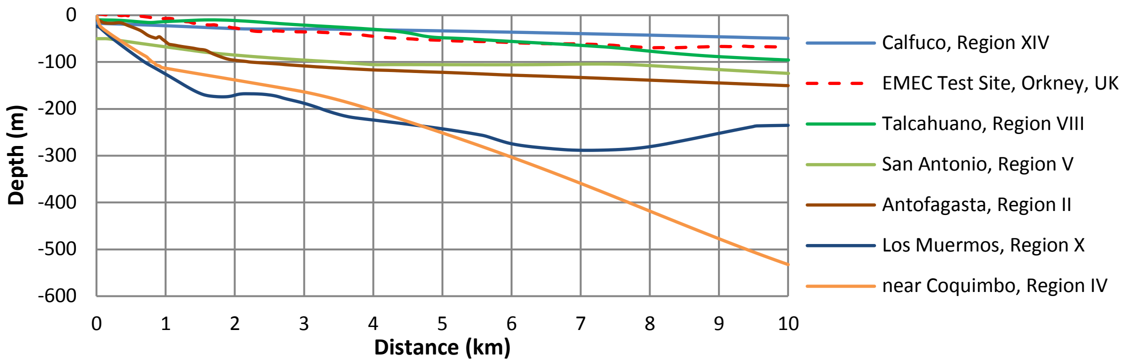


Figure 24: Comparison of seabed profile for Orkney, UK and Region IV of Chile

Technology adaptation implies the adaptation of marine energy devices developed abroad for Chilean conditions, but the characteristics and cost reduction priorities discussed here apply equally to the development of new Chilean marine energy technologies. Technology cost reduction and adaptation for Chilean conditions has already been included as a priority area in the Ministry of Energy´s draft Marine Energy Strategy and could be an important focus area for the planned marine energy ICE (see Recommendation 5-I, page 57).

5.4.2 Resource assessment and site selection to minimise cost of energy

There has been significant progress made on quantifying the total Chilean marine energy resource in recent years (Garrad Hassan, 2009) (Baird & Associates, 2012) (University of Chile, 2013), and results from the HydroChile-led study mentioned previously are to be made public in 2016. It is worth considering the different levels of resource quantification that exist, based on

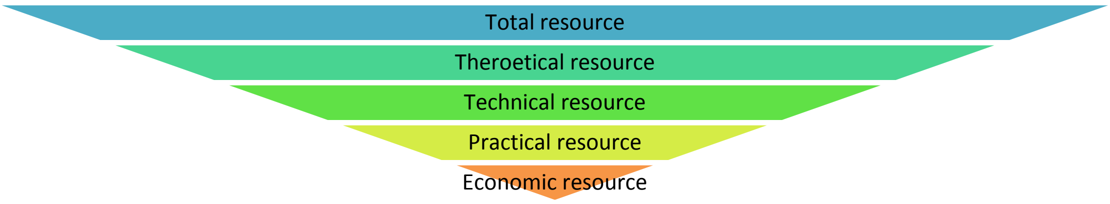


Figure 25: Levels of marine energy resource quantification

1. **Total Energy Resource** – the total energy that exists within a defined wave or tidal system. This includes both kinetic and potential energy.
2. **Theoretical Resource** – The maximum energy that can be harvested from waves or tidal currents in the region of interest beyond which attempts to extract more energy from the system actually reduce the overall energy that is harvested. No consideration of technical (including technology options) and economic (including project economics) constraints or arbitrary constraints on the underlying tidal hydrodynamic environment.
3. **Technical Resource** – the energy that can be harvested from waves or tidal currents in the region of interest **with** consideration of technical (including technology options) and economic (including project economics) constraints as well as arbitrary constraints on the underlying tidal hydrodynamic environment. The technical resource is a proportion of the theoretical resource.
4. **Practical Resource** – a judgment regarding the level of technical resource that would be acceptable to society. Considers external constraints (e.g. shipping, fishing, naval zones etc.).
5. **Economic resource** – this will vary for each technology considerably through time, depending upon the costs of inputs, grid connection and transmission, regulatory regime, costs of alternative technologies, etc.

Recommendation 5-A: Measured data on marine energy resources and seabed bathymetry.

Although the wave and tidal resources of Chile have been modelled, the number of sites where real measurements have been taken is limited. It would be beneficial if more measured resource data was available for tidal sites in the south of Chile (see Recommendation 2-D, page 11) but also for the most promising wave sites all along the coast of Chile.

Accurate seabed mapping (bathymetry) is of equal importance for the selection and evaluation of appropriate marine energy sites.

Industry / Academia **Short term**

Case study 5-E: Cost of energy studies (UK)

The development of the UK´s wave and tidal industry has been helped significantly by the strategic resource assessment work that has been carried out and the subsequent refinement of this work to consider the levelised costs of energy production.

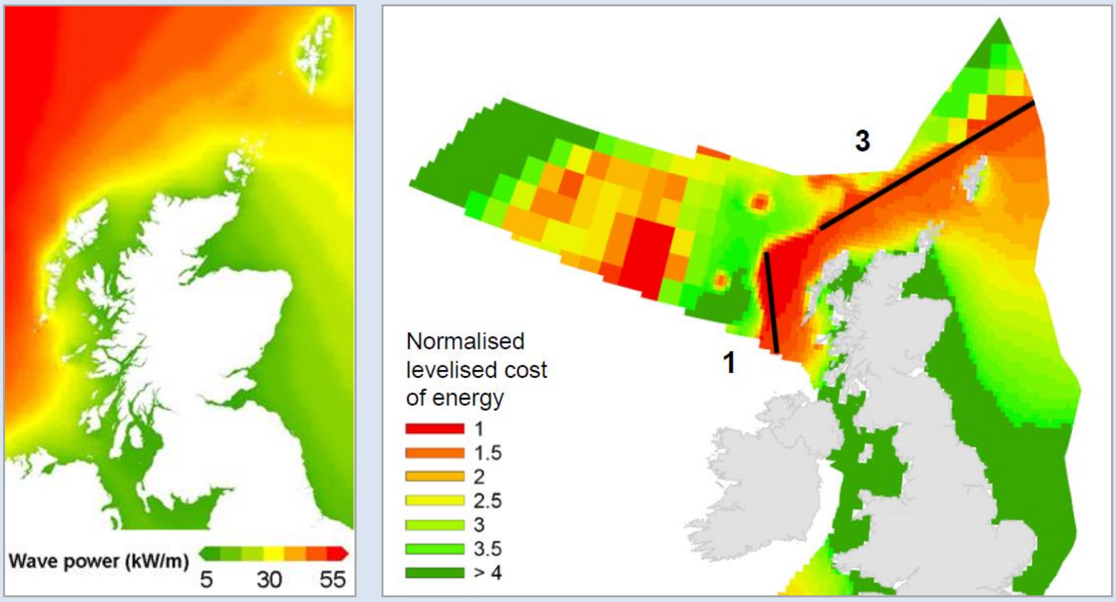


Figure 26: Scotland Wave Resource Map[12] (left) and Cost of Wave Energy Map[13] (right)

Figure 26 gives an example of the difference in output between a resource assessment study and a cost of energy study. Although cost of energy will tend to be lower in areas with higher resource, the consideration of other parameters will also have a significant effect (Figure 27).

Chile´s total marine energy resources are increasingly well understood, although the potential of tidal power in remote areas requires further attention. Regarding Chile´s most significant wave and tidal power sites, a sensible next step may be to use the information available about raw resource to develop a better understanding of where projects could be realised at most competitive cost.

[12] (University of Edinburgh, 2006)

[13] Note: black lines and numbers are for identification of offshore resources areas only. Normalised levelised cost of energy is intended to show areas of relative high and low cost. (AMEC/Carbon Trust, 2012)

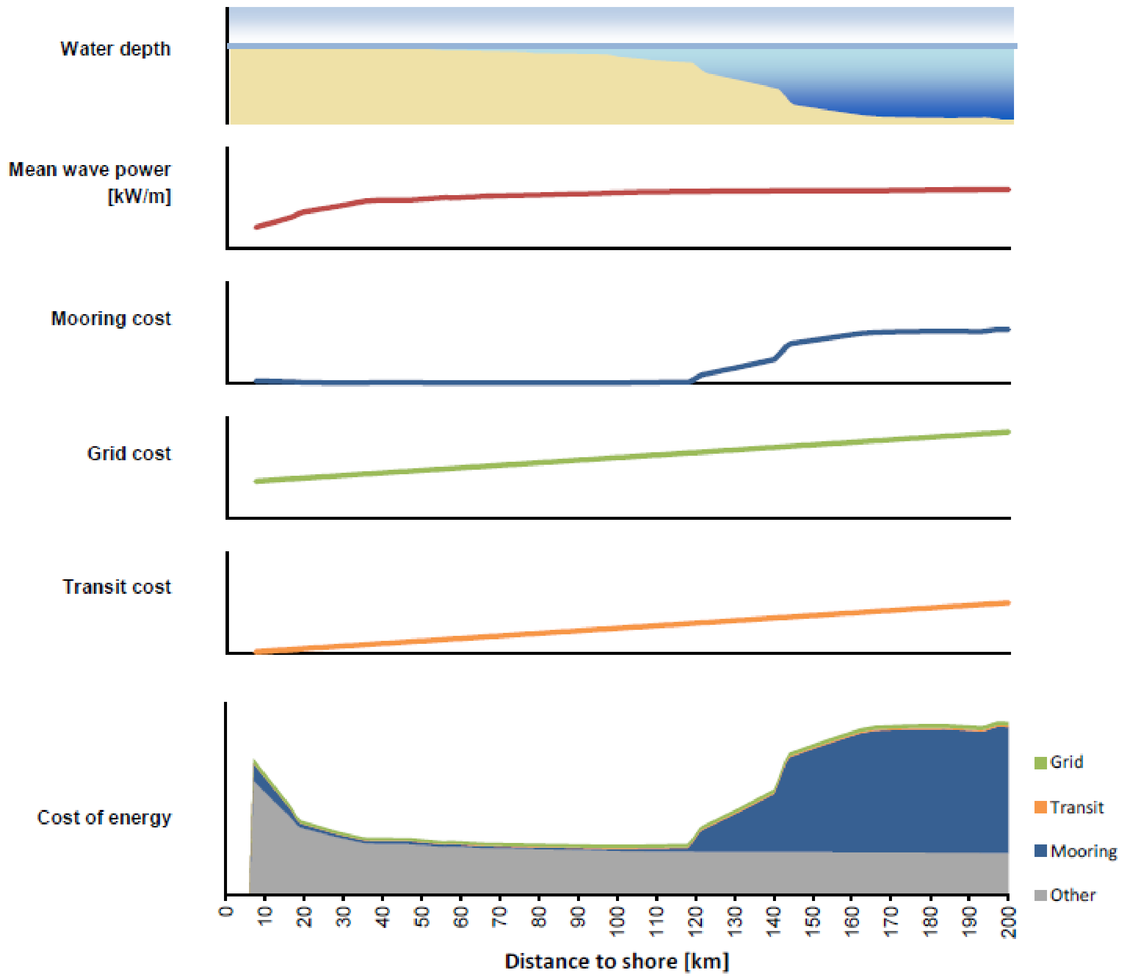


Figure 27: Cost of energy considerations – wave power example (AMEC/Carbon Trust, 2012)

Figure 27 shows some of the parameters which could be considered in national or regional cost of energy studies (Recommendation 5-B). Such work could support the identification of priority zones for development (Recommendation 4-L, page 26) as well as the development of individual sites. As shown in Table 5 (page 36), there are specific characteristics of Chilean sites which will affect these cost of energy evaluations.

Recommendation 5-B: Cost of energy study for Chilean wave and tidal sites

The Chilean **Ministry of Energy** may wish to consider funding a cost of energy study for wave and tidal sites in Chile, considering near shore or coastal as well as offshore devices. The results of this could support the identification and designation of priority development zones (Recommendation 4-L, page 26). The planned marine energy **ICE** could also be an appropriate organisation to carry out this work.

Regional Governments could also consider funding more detailed regional studies to support industry development.

Ministry of Energy / ICE **Short term**

5.4.3 Environmental research

It is impossible to undertake any industrial activity without some level of impact on the environment. Such impacts do therefore arise from marine energy projects and can influence physical, ecological, heritage, social, and economic features of the environment. The focus of impact analysis is often biased towards the negative influences of an activity, but in the case of renewable energy generation it is also important to consider the benefits that can arise.

The most important benefits to consider are the generation of carbon-free power and the associated reduction in the emission of greenhouse gases. There are also very important economic benefits that can arise and interesting consequences for existing marine activities – such as positive effects on fish stocks from the creation of no-catch zones and artificial reefs.

The possibility of such benefits does not however diminish the significance of any negative impacts. The main concerns to date have centred upon the effects of energy extraction on the local environment; disruption to the behaviour of sensitive species; influences on the heritage values of protected sites and features; and disruption to existing marine activities such as shipping and fishing.

5.4.3.1 Environmental sensitivities

Given the breadth of issues that need to be addressed across all parts of the project development process there are a number of sensitivities that need to be considered. These are outlined below in Figure 28. Such a holistic perspective on environmental issues will help to ensure that decision making, planning, permitting and monitoring processes are appropriate and effective.

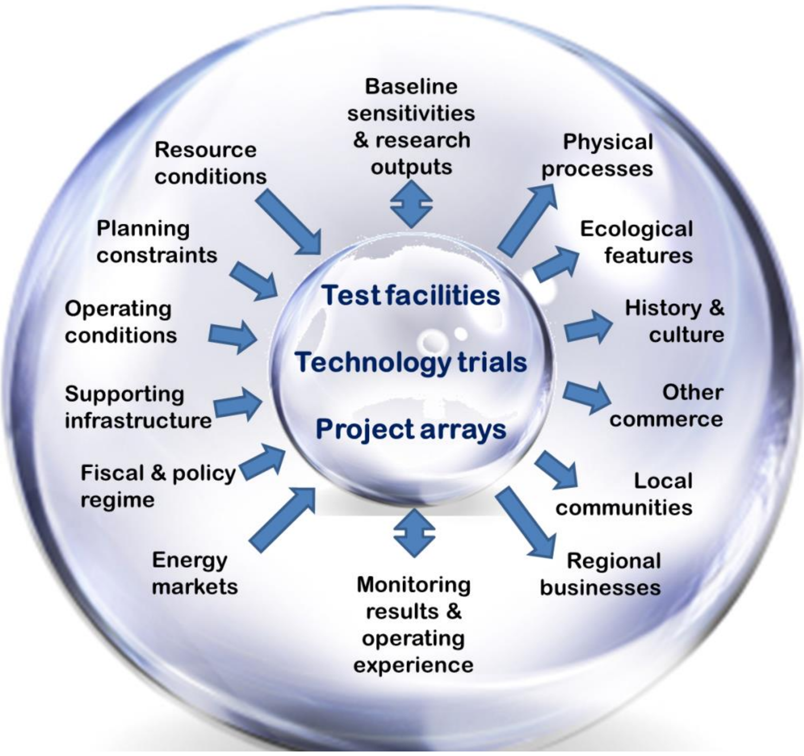


Figure 28: Key environmental interactions associated with marine energy projects

On the left hand side of Figure 28 some key effects of the environment on marine energy projects are presented. On the right hand side the potential effects of that project on the wider environment are listed (note that these include social and economic as well as physical and ecological impacts). The top of the figure shows the baseline research required before project initiation. The requirements for monitoring and learning from operational experience are indicated at the bottom.

5.4.3.2 Experiences to date

Deployment of modern marine energy devices in significant numbers began around the year 2000. Since then around 50 technology deployments at greater than 100kW scale have been completed. The results from these deployments can provide early information on the issues that are likely to materialise from the installation, operation and removal of larger farms of wave and tidal energy devices and related infrastructure.

To date few if any negative ecological impacts have been observed, whereas economic benefits and social benefits have been important, particularly in remote areas (see Case study 8-A, page 131). Perhaps surprisingly, for marine energy as for wind energy projects, opposition to the visual presence of power generating equipment can often be a more difficult consideration to resolve than any functional or ecological effects.

It is clear from the experience to date that applied marine energy research and particularly environmental research need to be prioritised and coordinated to secure the best results for the industry, see Recommendation 5-I at the end of this section.

Recommendation 5-C: Prioritise environmental research using a risk-based approach considering international experience; create an environmental working group to coordinate environmental marine energy research.

Given the importance of environmental research and the fact that many **Chilean Universities** are already active in this field, it may be of benefit to set up a working group to coordinate environmental research. The planned marine energy **ICE** could support this.

An international collaboration of this sort would also ensure that baseline and monitoring data is gathered in a coherent manner.

See also: Recommendation 4-H, in Environmental Impact Assessment , page 23.

Chilean Universities / ICE **Ongoing**

Case study 5-F: Prioritisation of research effort (USA)

University research centres (such as the Northwest National Marine Renewable Energy Center) and national laboratories (such as Pacific Northwest National Laboratory) in the United States are active participants in marine energy related environmental research. Figure 29 demonstrates how, by considering the potential significance and uncertainty around interactions between devices and the environment, research effort can be prioritised to focus on the most important areas.

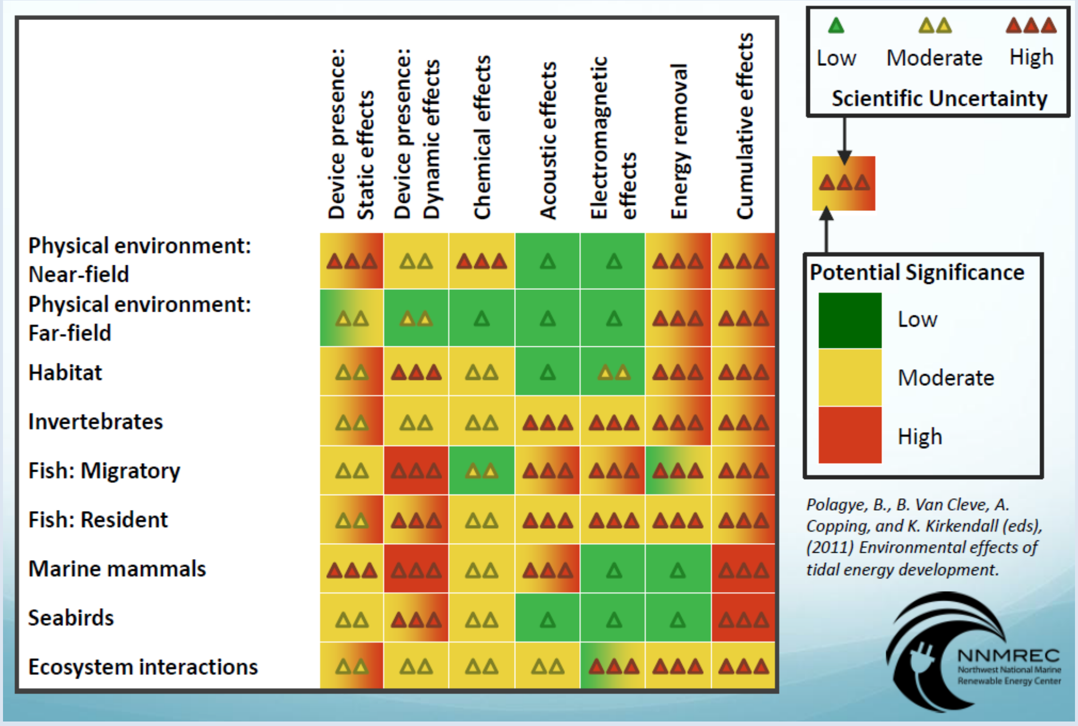


Figure 29: Example of prioritisation of research effort by uncertainty and significance

(Polagye, et al., 2010) from (NNMREC, 2013)

Another key point to take from this example is the significant uncertainty around cumulative effects – the ecological effects recorded from individual device deployments have been insignificant but the effects of large scale deployments have still to be determined.

Environmental research must to a large extent be done locally, and it can be difficult to assess environmental risks when limited information about the existing conditions is available. Whilst the gathering of some amount of baseline data is essential, it is best to prioritise this work on a risk basis.

The tables on the following pages present a qualitative review of the environmental interactions which have been observed to date from wave and tidal energy projects, based on Aquatera´s experience and knowledge.

Table 6: General overview of environmental interactions to date from wave energy projects, based on Aquatera´s knowledge and experience

Key:	Severe	Major	Moderate	Minor	Negligible	None	Positive

Issue	Environmental interactions from wave energy projects
Physical	
Sea conditions	**Minor**: Wave devices take their highest proportion of energy out of moderate waves. Key processes are often shaped by storm conditions, when devices tend to shed energy. Therefore there is little likelihood of marked effects.
Seabed	**Minor**: No measurements made, but modelling has suggested some build-up of sediments in the wave shadow of an array, albeit not to a pronounced level.
Energy flux	**Minor**: Generally low sensitivity in ecosystem to reduced energy flux. A few species are adapted to extreme energy, e.g. *Fucus Disticus* in Orkney. Plankton succession could be changed in significant wave shadow areas if stratification starts earlier in season.
Noise	**Negligible**: Devices are designed not to emit noise and many operate very quietly. Waves, current and vessels (which input rather than extract energy) are the dominant noise sources. Some short-term construction noise.
Seascape	**Major:** Exposed coastal areas can represent wilderness type areas, often with little human influence. Such areas may merit protection from near shore wave energy developments.
Coastal processes	**Negligible:** Along rocky shores there is little potential for change, and even on sandy coasts most change occurs during storm events, which remain little changed by most wave energy devices.
Ecological	
Plankton	**Negligible:** No direct effects anticipated. Possible that a distinctive wave shadow could alter water column mixing dynamics and thereby change the succession of species in the influenced area. This would have to be at very large scale (i.e. >10km^2 shadow area) before it could be significant.
Benthos	**Negligible to positive**: Direct effects occur from the placement of anchor and mooring systems and also from cable laying and burial. Experience has shown that the scale of negative impact will be rather small and most likely negligible in significance. Devices create obstacles to bottom trawling which help to protect seabed communities.
Fish	**Negligible to positive:** Most likely effect is attraction and aggregation around the structure (device plus moorings) creating a 'reef effect' . Concerns have been raised about the migration of conservation designated species e.g. salmon, but no evidence to support this. Devices will create obstacles to trawl fishing which will help to protect local fish stocks.
Sea mammals	**Negligible:** Potential interactions with wave devices are benign as these devices are relatively slow moving and generally located in areas of low current. Some concerns about entrapment of some species in densely populated areas.
Sea birds	**Negligible:** There are no established mechanisms for direct effects, seabirds seem oblivious to the devices deployed so far. Some sea-duck and diver populations have however been displaced by offshore wind farms in the North Sea.

Issue	Environmental interaction from wave energy projects
Heritage	
Geology	**Negligible:** Very localised disturbance from cable trenching, if required.
Species	**Negligible to positive:** Direct negative effects upon species from devices are generally negligible, exclusion of trawl fishing will often help protected species.
Habitats	**Negligible to positive:** Direct negative effects upon habitats from devices are generally negligible, exclusion of trawl fishing will often help protected habitats.
Landscapes	**Minor to major**: Impact will vary depending on the technology, but near shore devices may fail to get planning approval in certain sensitive and highly valued coastal areas.
History	**Negligible:** Little scope for direct disturbance to historical artefacts, some potential to influence the designation of coastal protected areas.
Social / economic	
Demographics	**Positive**: Population in Orkney has increased by 10% over 10 years, in part due to renewables jobs. Wave energy can help create challenging jobs for young people, helping to stop the flow of talent away from remote areas.
Infrastructure and supply chain	**Positive:** Wave energy will stimulate infrastructure and supply chain development. Local jobs created, some of these (e.g. operations support) will be long term. Service providers may gain experience and expertise that they can then apply to other markets. There can be competition for berthing space in small ports until purpose built facilities are available.
Other sea users	**Moderate:** There could be some disruption to fishing and shipping activities and cable laying from the testing and deployment of wave energy devices.
Energy	**Positive:** Renewable energy projects reduce greenhouse gas emissions and local pollution. The diversity, security and independence of energy supply can be improved. New energy management, storage and transmission systems may be required.

Table 7 on the following page presents the same analysis for tidal power projects.

Table 7: Overview of environmental interactions to date from tidal energy projects, based on Aquatera´s knowledge and experience

Key:	Severe	Major	Moderate	Minor	Negligible	None	Positive

Issue	Environmental interaction from tidal energy projects
Physical	
Sea conditions	**Minor:** Supporting structures and navigational markers in tidal flows may create disturbances around them which could be a hazard to smaller craft.
Seabed	**Negligible:** Seabed in tidal sites is generally bedrock or gravel and cobbles. Little or no potential for scour, direct disturbance from device foundation and cables has only very limited footprint.
Energy flux	**Minor:** Amounts of energy extracted generally limited to less than 10% of flow before 'blockage' effects start to occur. Some interference in the circulation of nearby water bodies expected.[14]
Noise	**Negligible:** Vessels (which input rather than extract energy from the water) are the greatest source of noise and significant ambient noise is usually present. Some short-term construction noise.
Seascape	**Moderate:** The devices may be visible and support vessels and substation platforms will be visible, and generally near to the shore. In populated areas such channels are often well used shipping channels or ferry crossings.
Ecological	
Plankton	**Negligible:** No direct effects, possible downstream changes to circulation and residence times of current influenced water bodies.
Benthos	**Minor:** As with seabed the fauna will be little affected, may need to take care if fragile biogenic reefs are formed in current swept areas. More sensitive communities along cable routes to shore.
Fish (smaller species)	**Positive:** Any structures may have a reef affect, acting as an attraction during slack water and offering some shelter during tidal flow. No evidence of strong collision risk.
Sea mammals, turtles and large fish	**Moderate:** There are concerns about possible collision risks for seals, sea lions, turtles, basking sharks and cetaceans. To date no examples have arisen and behavioural avoidance has been indicated from monitoring results.
Sea birds	**Positive:** Certain seabird species, particularly underwater pursuit predators, adopt devices as a new hunting habitat, especially at or near slack water.

[14] (Bryden & Couch, 2004)

Issue	Environmental interaction from tidal energy projects
Heritage	
Geology	**Negligible:** It is unlikely that protected geological features would exist in the channels themselves, but areas around coastal cable landfalls may be. Site selection or careful engineering can avoid harm.
Species	**Moderate:** Concerns about collision risk with larger sea life, mentioned above many of these species are protected.
Habitats	**Minor:** Little potential for effects beyond the immediate surroundings of the device.
Landscapes	**Minor:** Most devices are underwater (unlike for wave). Cable landings and substations may be a more important consideration than the devices.
History	**Minor:** Tidal streams are home to some ship wrecks but in general there are few historically valuable features in the tidal streams themselves.
Social / Economic	
Demographics	**Positive**: Population in Orkney has increased by 10% over 10 years, in part due to renewables jobs. Tidal energy can help create challenging jobs for young people, helping to stop the flow of talent away from remote areas.
Infrastructure and supply chain	**Positive:** Tidal energy projects will stimulate infrastructure and supply chain development. Local jobs created, some of these (e.g. operations support) will be long term. Service providers may gain experience and expertise that they can then apply to other markets. There can be competition for berthing space in small ports until purpose built facilities are available.
Other sea users	**Moderate:** There may be some disruption to fishing and shipping activities and from the testing and deployment of tidal energy devices, particularly in busy channels.
Energy	**Positive:** Renewable energy projects reduce greenhouse gas emissions and local pollution. The diversity, security and independence of energy supply can be improved. New energy management, storage and transmission systems may be required.

5.4.4 Market niches

Markets niches exist within marine energy that have received comparatively little attention or support to date. Certainly the overwhelming focus in Europe has been on developing MW-sized devices for grid-connected electricity production. Chile´s extensive mining sector, communities in water-deprived areas, the salmon industry and remote off-grid communities may present opportunities for Chile to take a lead in applications of marine energy which could make commercial sense before the delivery of electricity to the national grid.

5.4.4.1 Mining

Chilean mining activity is concentrated in the north of the country, in one of the most arid deserts in the world. Water supply has historically been one of the industry's main problems. This has been exacerbated in recent years by an increase in mining activity, an increase of population and the depletion of water sources by over exploitation. In recent years, the mining industry has looked urgently to the nearest water source: the sea. The industry´s demand for desalinated water is set to grow by at least 400% over the next four or five years (BNamericas, 2013). The Chilean Government estimates that by 2020 the copper mining industry may need 6.3TWh of energy annually, just to satisfy desalination and water pumping requirements. Table 8 below shows some key Chilean mines using seawater or desalinated water in their operations.

Table 8: Some mining operations using desalinated water or seawater in Chile (GWI, 2011)

Company	Operation	Feedwater	Capacity (m^3/day)	Investment/Cost (USD)	Status
BHP Billiton	Coloso plant at Escondida	Desalination	45,360	$200 million ($50 million for plant and $150 million for pumping system)	Operating since 2006
++ Minerals	Michilla Mine	Direct use of seawater for leaching	6,500	unknown	Operating since early 1990s
Antofagasta Minerals	Esperanza	Direct use of seawater for copper flotation	62,200	$2,3 billion (mine project including pipeline)	Started operating in 2011

To satisfy the needs of the cities as well as the mining industry in the north of Chile, large seawater desalination plants have been built. Costs are high, and local authorities and industries are actively exploring the alternatives that could be offered by renewables, including marine energy.

The wave potential of the north of Chile is lower than the south, but at around 20 to 25kW/m – is still sufficient for power generation and is highly consistent (see Figure 37). Identifying and developing the best solutions for wave-powered seawater pumping or desalination could allow Chile to take the lead in this market. Tidal resources are however minimal in this area.

Of course in addition to water, mining requires a huge amount of energy: copper mining alone is responsible for 30% of all electricity consumption in Chile (Ministry of Mining, 2012) and mining uses around 90% of the electricity generated in the SING. There is enormous potential for marine energy to supply electricity to the mining industry throughout Chile and the majority of the RD&I effort internationally has been focused on the development of MW-scale machines for grid-connected electricity production which would be suitable to meet these needs. There are interesting opportunities for coordinated research into which electricity producing devices are most appropriate and how they might be integrated.

It may however be at least if not more interesting for Chile to consider prioritising technology development of wave power devices which desalinate or pump seawater (although the former could be limited by altitude). This is an area which has received comparatively little research attention to date and the potential, particularly in northern Chile, is vast. As with any pre-commercial renewable energy technology, concerns around reliability would need to be resolved, and it may be interesting to consider how wave power devices might reduce the load on existing or modified plant rather than developing stand-alone systems.

Recommendation 5-D: Market niches - wave-powered desalination and water pumping for the mining industry

The **Ministry of Mining**, in association with **CORFO** and the **Ministry of Energy**, may wish to consider undertaking a study considering the national potential for marine energy to provide pumped and desalinated seawater to the mining industry. This study could also consider the scale of the mining industry's renewable energy market in general, including and the potential for example for solar and wind to contribute. The planned marine energy **ICE** may wish to consider this niche market as a focus area for RD&I activity.

Chilean Government / ICE **Short term**

5.4.4.2 Drinking water supply

Cities in northern Chile rely increasingly on desalination for their drinking water needs, and many isolated communities have their drinking water brought in by road tanker. The potential for wave power to supply these areas with fresh water is significant, and as mentioned this is an area of marine energy development which has received little attention to date compared with the focus on producing grid power.

Recommendation 5-E: Market niches – wave-powered desalination for drinking water

The **Chilean Government** may wish to consider how RD&I focused wave –powered desalination could be supported in Chile. The planned marine energy **ICE** may wish to consider this as a focus area for RD&I activity.

Chilean Government / ICE **Short term**

5.4.4.3 Aquaculture/Salmon

The aquaculture sector in Chile has experienced a sustained growth in recent decades - in 2012 a total number of 3,200 marine concessions were held for Aquaculture cultivating 18 different species. By far the most significant activity is in salmon, which accounts for 93% of aquaculture exports (SUBPESCA, 2012). In addition to the concessions held there are more than 5,900 aquaculture concessions in the process of application.

Figure 26 gives an example of the density of salmon farming operations in the south of Chile. The salmon farming industry is a significant economic driver in Chile, particularly in remote areas - each red dot on the map represents one salmon farming concession.

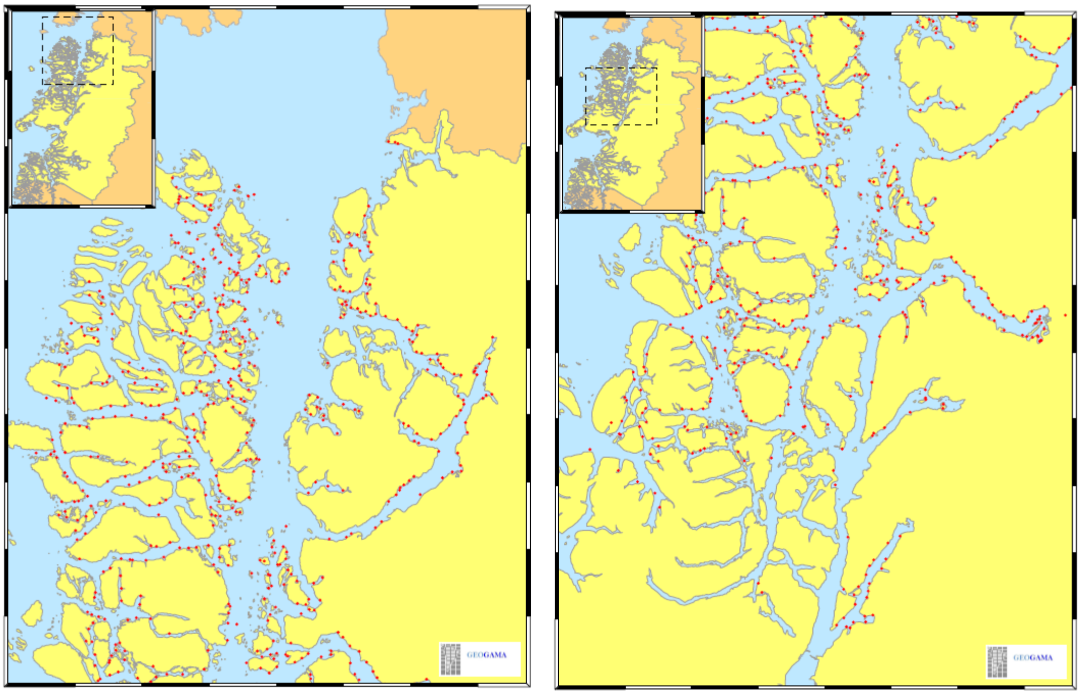


Figure 30: Salmon farming sites in Aysén - Region XI[15] (Source: GEOGAMA)

[15] For more information contact consultas@geogama.cl

Many aquaculture concessions are found in the fjords and channels of southern Chile (see maps in regional chapters), which implies significant logistical challenges and high costs of operation, especially in terms of energy. A typical salmon farm (cultivation site) requires around 250kW of electrical power, which is commonly generated with diesel engines. Although the cages themselves are generally moored in sheltered locations, there can be significant currents or waves nearby, and increasingly more exposed sites are being developed. There is a notable potential (currently being investigated in detail by Austral University) to supply salmon farms with power from local wave or tidal resources.

Salmon farms have however very specific requirements for energy (due to feeding cycles), and will require integrated energy management systems in order to accommodate fluctuating renewable energy supply alongside their operations. Replacing or at least reducing diesel consumption would have logistical, operational and environmental benefits as fewer fuel supply journeys would be required, plus operating costs, emissions and the risks of spills would be reduced.

Recommendation 5-F: Market niches – marine energy systems for salmon farms and other isolated power users

The **Chilean Government** and **Regional Governments** may wish to consider how RD&I focused on marine energy systems for salmon farms and other isolated communities could be supported in Chile (ref. Recommendation 7-A, page 86).

The planned marine energy **ICE** may wish to consider this as a potential focus area for RD&I activity.

Chilean Government / ICE **Short term**

Recommendation 5-G: Market niches - marine energy systems for isolated communities

The **Chilean Government** may wish to support the development of Chilean expertise in small-scale marine renewable technologies targeted specifically at remote and isolated communities.

The planned marine energy **ICE** may wish to consider this as a focus area for RD&I activity.

See also: Recommendation 7-A in Finance section 7.5, page 86.

Chilean Government **Short term**

5.4.4.4 *Isolated communities (energy and water)*

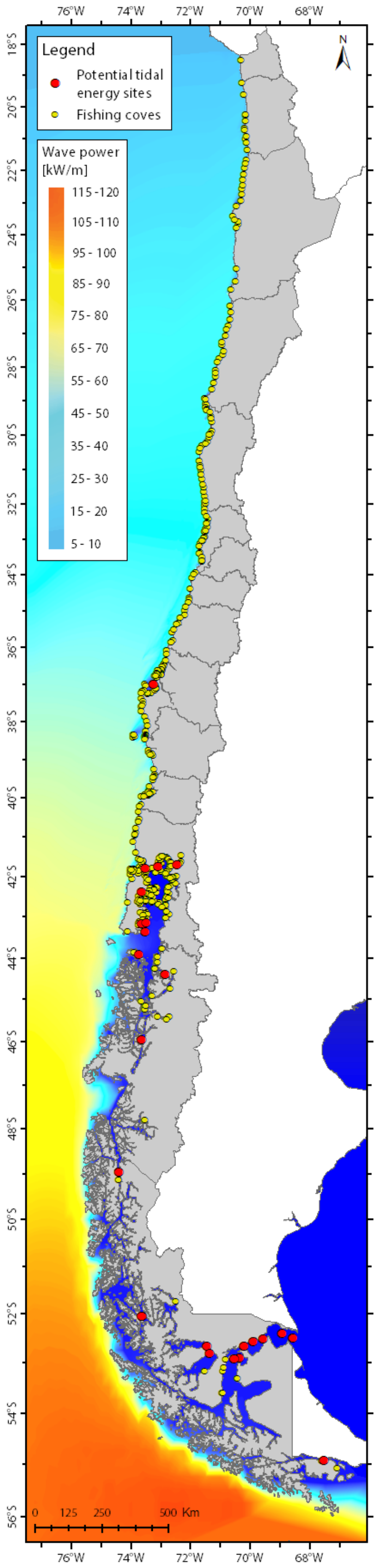
Chile has more than 3,500 isolated communities, many of which have limited access to basic services. The Chilean Sub-secretary for Regional Development has a program for remote communities, under which each region defines development goals.

Especially in the northern and southern extremes of Chile, there are many coastal communities which are extremely isolated, either by distance or difficulty of access. These communities face multiple challenges, but not least in access to clean water and affordable electricity in locations where high-cost diesel is often the only source of power. The future potential for marine energy to provide affordable electricity and desalinated water to isolated coastal communities and fishing communities is significant. Fluctuating renewable energy sources such as wave and tidal will require diesel back-up or energy storage and management systems to maintain production when the tide is not running or the seas are calm. An isolated community energy strategy could examine the potential for a number of technologies to operate in parallel, to offer lower-cost energy security for off-grid communities.

Many wave and tidal technologies are being developed to produce many MWs of commercial-scale utility grade power which can compete with low cost alternatives including other renewables. Such technologies may not be suitable for isolated communities or, if installed as single units, may have a significantly higher cost of energy than if deployed in farms of many units where economies of scale can be achieved.

There may be an opportunity for Chile to establish a leadership position in the development of small scale wave and tidal technologies. Although smaller scale technologies do not benefit from the same cost reduction through economies of scale as large projects, neither do they need to meet the same cost reduction targets as those deployed at the utility scale, as they are seeking to compete with diesel generation or other micro-renewables. Development of such technologies would have significant market opportunities not only in Chile but throughout South America, and could help pave the way for larger grid connected projects through the development of expertise and supply chain capacity.

It is also worth noting the tax breaks and free trade zones available in Chile´s remote regions (see Finance chapter 7) which could support projects in these areas.



5.4.5 Marine energy test sites – form, function and purpose

There are perhaps 20 marine energy test sites established around the world including dedicated multi-user test sites (such as EMEC in Orkney, Scotland) as well as other locations where single devices (such as Hammerfest in Norway or the island of Islay in Scotland). Each of these has unique features, provides different sets of services and was established for a variety of different political, practical and economic purposes. Factors which can describe a test site are presented in Figure 31.

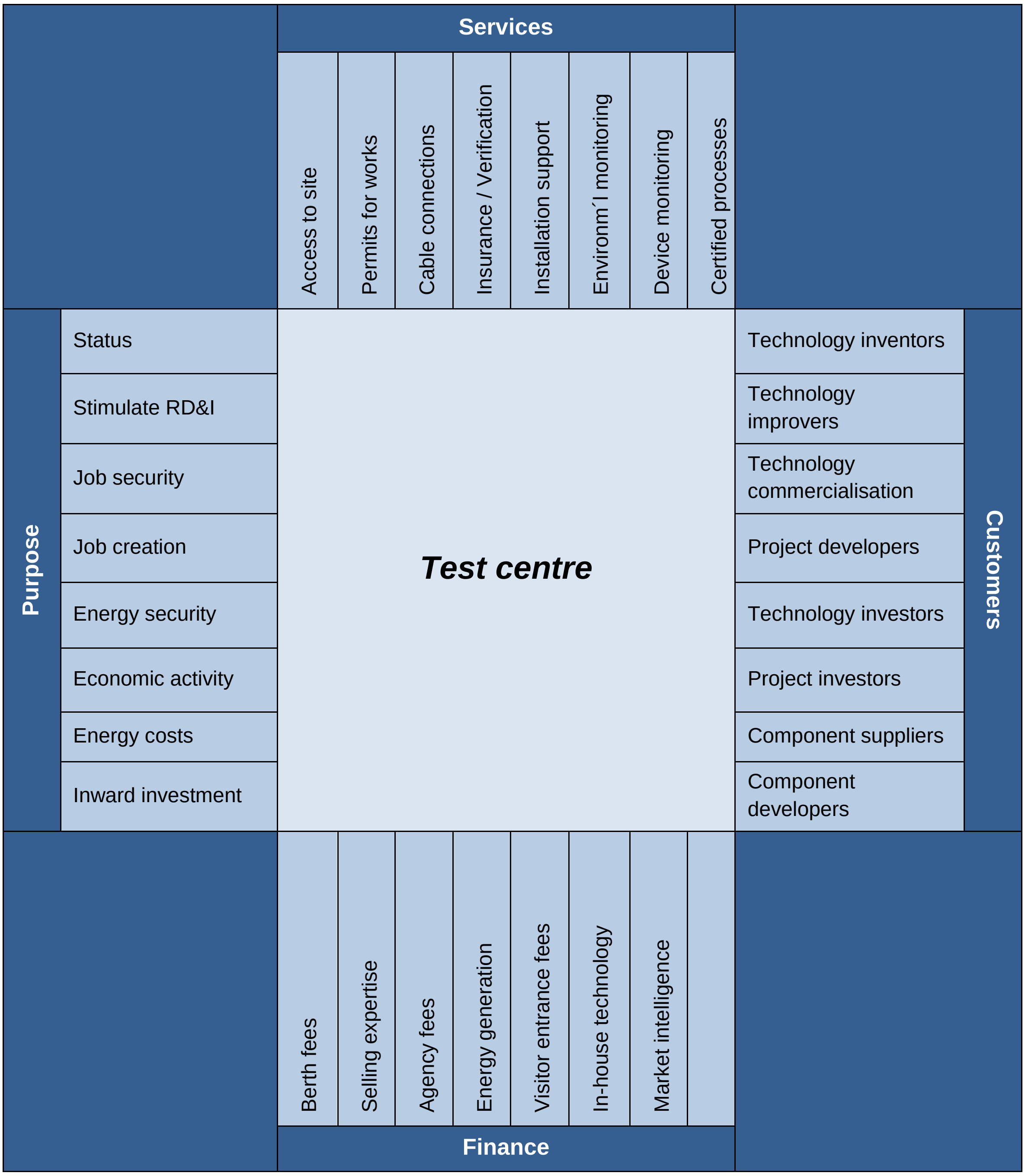


Figure 31: Schematic of elements that may contribute to a marine energy test centre

In any location that is keen to promote and establish marine energy an early question is likely to be - is a test site needed?

The first aspect to consider is the consequences that have arisen from establishing previous test sites. There are a number of other sites that have been, or are being set-up, and a number of their stories are also presented in the case studies.

What is common across all of these test sites is the level of challenge associated with securing funding and finding the right place for establishing the sites. Other key lessons learned from these experiences are:

- Market use of a site has almost always been slower than planned;
- Early technology deployments are often associated with technical delays, breakdown and wear which lead to operational problems;
- Test sites can provide a focus for development of the surrounding supply chain;
- Test centres need to deal with marine planning issues in a similar manner as any other development;
- Many of the users of test sites are by definition under pressure technically, financially or both.

Given the state of the industry, the appetite in government for providing support to the sector, and the experiences seen arising elsewhere, it is not surprising that there are calls for and interest in establishing some form of marine energy test site in Chile. The key questions that need to be addressed are as follows:

- Is the test facility for wave energy, tidal energy, or both?
- Does the facility need to be in one place?
- What is going to be tested (devices, systems, components)?
- What scales of devices are to be tested?
- How much funding is available?
- Is the facility going to be grid connected?
- Who is going to own and operate the facility?
- What services, support facilities and funding will be available to users?
- How long can the site be used for?
- Etc.

There are three initiatives already underway that could be strongly associated with establishing a suitable test facility in Chile. These are the two proposed technology pilot projects and the proposed project to establish an ICE. Although none of these initiatives is explicitly required to establish an enduring test facility it can be foreseen that each project has the potential to provide a smaller or larger part of any facility that may be needed.

Based upon the above, the findings of the workshops and the needs analysis completed, it is apparent that:

- Chile would benefit from establishing a wave and tidal test site or sites.
- A test site is distinctive and different from a centre of excellence or one-off pilot projects, although if desired these initiatives can be combined.
- Providing rapid access to a site in terms of establishing suitable concessions and licenses is a major benefit.
- Specifying and providing cable connections to shore and onward grid connections is a secondary benefit which may be better provided as part of a technology deployment.

- Strong consideration should be given to providing installation support through any site support.
- Verifying structural and component integrity at foreseeable deployment scales is critical.
- Establishing functional verification of design elements should take place at practical scales – often smaller and man-manageable is better.
- Any test site and associated facilities will need to establish basic quality standards within which users will be required to operate.
- The availability of a supporting supply chain and related infrastructure will be of critical importance to any test site related initiative.
- Testing area may comprise a number of single device and small array berths.
- Larger and smaller scale sites providing for wave and tidal devices at different scales can be a benefit.

If a marine energy test site, or sites were established in Chile there would also be opportunities for a number of secondary benefits from related activities, which could include:

- Offshore wind testing
- Maritime industry technology testing
- Offshore oil and gas technology testing
- Physical platforms for instrumentation and data gathering
- Focus point for other research

Lessons learned from setting up device testing centres include:

- Ensuring that infrastructure is suitable for future technology deployments (and if possible for commercial expansion) – internationally there have been examples of submarine electrical equipment being installed which has subsequently proved to be inappropriate for marine energy device developers.

- It should be noted that it has taken a decade for EMEC to become fully established as a global test centre, even though it is adjacent to the world’s largest area of commercially leased seabed, all eligible for full Scottish Government market support (see Case study 11-A, page 147).

- Choosing an appropriate operational model for marine operations is important i.e. who controls access to and operations on site, is a permit to work system used, etc.

Case study 5-G: Marine Energy Centres

In the UK there are three test sites which cover the various stages in the wave/tidal energy device development, these are described below.

NAREC (National Renewable Energy Centre) **-** Opened in 2002 at Blyth in the north west of England. Carries out scale testing of marine renewable devices and sub-systems.

1. 3 Dry Docks – the largest of which is 75m long, 25m wide and 8m deep
2. Wave Flume - A simulated wave environment for the testing of prototype wave energy generation devices sited within a converted dry dock facility.
3. Nautilus - A 3MW drive train test stand for tidal energy generators which allows certification activities, reliability and performance appraisal of new devices through accelerated lifetime testing at significantly lower cost and risk in comparison to sea testing.
4. Tidal Testing Facility – The Tees Barrage Tidal Turbine Test Facility, located in Stockton, was opened in 2007.

EMEC (European Marine Energy Centre) **-** Prototype development

EMEC is based in Orkney within the Pentland Firth and Orkney Waters marine energy park. It was established in 2003 and has expanded and diversified its testing facilities, attracting wave and tidal energy developers from around the globe. EMEC is the first and only centre of its kind in the world to provide developers of both wave and tidal with accredited open-sea testing facilities. To date it has had the largest number of marine renewable device deployments within its wave and tidal test sites.

The centre has been the focus of a large amount of developer attention and global interest and as such has also attracted a large media focus. The success of the centre has also encouraged the local supply chain to build up and is increasingly the focus for research and education. EMEC also operates scale (nursery) test sites where smaller scale devices (or those at an earlier stage in their development) can gain real sea experience but in more benign conditions than those experienced at the full-scale wave and tidal test sites.

Wave Hub **-** demonstration and proving of arrays

Wave Hub is a grid-connected offshore facility in South West England for the large scale testing of technologies. It consists of an electrical hub on the seabed 16 kilometres off the north coast of Cornwall in South West England to which wave energy devices can be connected. The project holds a 25-year lease for eight square kilometres of sea and has four separate berths, each with a capacity of 4-5MW.

Recommendation 5-H: Implementation of pilot projects and coordination with the ICE.

It would be beneficial if the pilot projects could be set up in a timely manner as delays can reduce confidence in the sector.

The planned marine energy **ICE** and **Pilot Projects** may wish to consider developing a formal cooperation agreement to ensure that the testing of full scale devices is coordinated with the research lines of the centre across areas such as components, materials, operational and maintenance strategies and environmental work.

There are now a number of existing marine energy test and research centres close to the centres of technology deployment activity in Europe and North America. It would be beneficial to ensure that the Chilean research centre and pilot projects are set up in coordination with these centres, to transfer lessons learned and avoid duplicating efforts.

ICE / Pilot projects **Urgent**

5.5 Conclusions – research, development and innovation

New ocean energy research programmes in Chile need to be complementary to those already in existence. A number of studies have examined the challenges and research needs of the ocean energy sector:

- Accelerating Marine Energy. The Potential for Cost Reduction – insights from the Carbon Trust Marine Energy Accelerator (Carbon Trust, 2011)
- Marine Energy Technology Roadmap (ETI/UKERC, 2010)
- Technology Innovation Needs Assessment (TINA) – Marine Energy Summary Report (LCICG, 2012)
- Report of the Research Prioritisation Steering Group (Forfás, 2011)

One clear lesson to be taken from European experience is to ensure that research is aligned to industry needs. By bringing academia and businesses together, research requirements can be identified which have the biggest impact. It is important that any research prioritisation process takes account of practical experience as well as the published literature.

Recommendation 5-I: Establish ICE to lead on strategic national research projects; create national plan for marine energy RD&I

It would be beneficial if the planned Chilean marine energy **ICE** could be set up in a timely manner. The **ICE** could be a suitable organisation to develop (in partnership with the appropriate national and international agencies) a Chilean plan for marine energy related research, development and innovation activity. The development and maintenance of this plan could be managed by a steering group with representatives from for example **Chilean Universities** and **RD&I centres**, **InnovaCORFO**, **CONICYT** and appropriate international organisations, who could also contribute to the proposed periodic reviews of marine energy strategy (Recommendation 4-P, page 30).

InnovaCORFO / ICE — **Urgent**

Recommendation 5-J: Hold regular marine energy RD&I conferences; publish findings

Chile´s RD&I community has already held marine energy events and published marine energy research. Regular conferences and the publishing of findings should be encouraged, to enable better coordination of research and dissemination of results.

Chilean RD&I community — **Ongoing**

Recommendation 5-K: Formalise links with existing marine energy forums (EUOEA/UKERC)

It may be beneficial for members of the Chilean RD&I community (e.g. Universities and applied research centres) to formalise links with existing marine energy forums such as the European Ocean Energy Association (EUOEA) or the UK Engineering Research Council (UKERC).

Chilean RD&I community — **Ongoing**

Recommendation 5-L: Catalogue of research capacities and facilities

The National Science and Technology Research Commission (CONICYT /FONDECYT) may wish to consider establishing a catalogue of capacities and facilities for sharing in the international market place, in partnership with Chilean Universities and RD&I Centres.

CONICYT and others — **Ongoing**

6 Infrastructure and supply chain

The third pillar of the Ministry of Energy´s draft Marine Energy Strategy relates to infrastructure and supply chain.

As with any emerging industrial sector, the development of a successful and economically viable marine energy industry will be fundamentally linked to the availability and capacity of the necessary infrastructure and a suitable supply chain. These factors are so fundamental that they can slow-down, delay or even block developments that are otherwise perfectly viable. Although considered together in this chapter and containing many dependencies, either infrastructure or supply chain deficiencies on their own are also important enough to lead to development problems. Any progress that is to be made and success that is achieved must be built upon strong infrastructure and a strong supply chain.

Due to the status of the marine energy sector as a future prospect, rather than an existing reality, it can be unclear what infrastructure will be required to support the varying scales of potential development and how this may link in with existing available infrastructure.

A particular issue for marine energy is that the exploitable resource areas are limited to specific sites and can be located far from existing urban and industrial areas. Major components of the supply chain required to deliver marine energy projects may exist to a large extent but will be required to adapt to the unique challenges and opportunities of the sector.

It is worth noting that Chile does not necessarily need to “own” marine energy technology to benefit from building local supply chain activity (although playing a leading role in technology development would have other benefits). As seen in the UK (Aquamarine Power, 2013), a lot of the supply chain has to be based locally, from environmental assessment to dive teams, and it often makes sense to manufacture locally, even if the technology was developed elsewhere.

In the short term, the focus of the Chilean marine energy industry is likely to be on RD&I and relatively small-scale projects located in areas where appropriate infrastructure is already in place. In the medium to long term however, new and improved infrastructure and specific supply chain capacity-building may be required.

This chapter considers the following key areas:

- Electricity grid – the power transmission lines and regulatory regime required to transport power generated from marine energy project to the consumer;
- Maritime and industrial infrastructure – the major fabrication yards, ports and vessels required to build, install and maintain marine energy devices;
- Supply chain – the supporting (and overlapping) web of the services, equipment and minor infrastructure which are required through the life cycle of marine energy projects;
- Skills – the requirements for training and development of people with the expertise and ability to make projects successful.

6.1 Electricity grid

Chile´s National Energy Commission´s 2009 report, “Non-Conventional Renewable Energy in the Chilean Electricity Market” (CNE & GTZ, 2009), provides a comprehensive review of developments in the Chilean electricity market and outlines the measures being put in place to accelerate the incorporation of renewable energy projects into Chile´s electricity system.

As an energy sector, marine renewables will require electrical infrastructure such as:

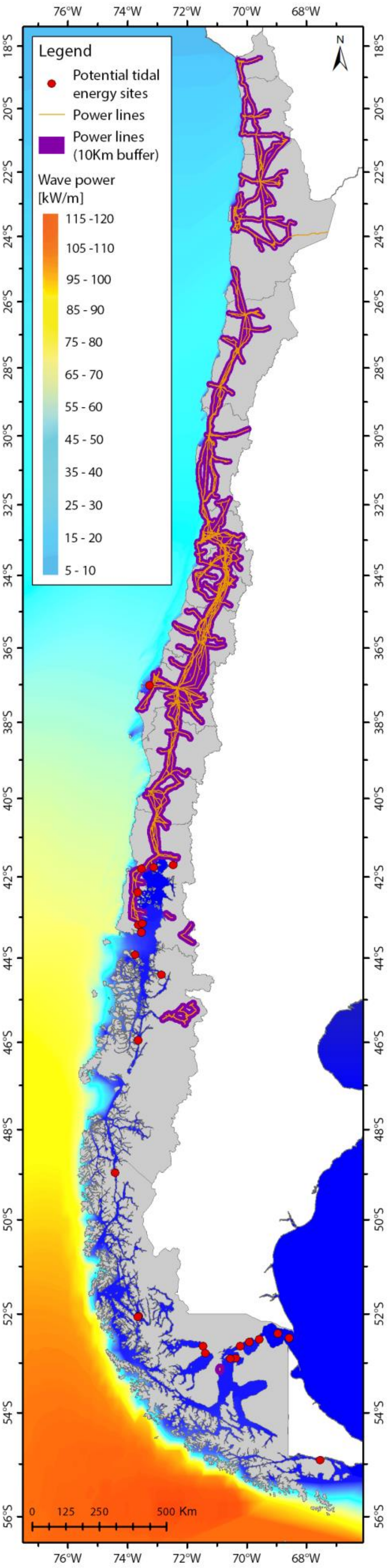
- Grid connections (subsea cables)
- Sub stations
- Transmission grid (AC and HVDC)
- AC/DC converters
- Back-up power supplies

In Chile in recent years, there have been several positive changes made to the electricity market and regulatory system to encourage renewable energy development:

- Small generators can now participate in the electricity market;
- Partial or total exemptions of transmission charges have been introduced for small scale NCRE projects;
- All electricity companies selling energy to final consumers are obliged to supply a percentage of the energy they sell from NCRE sources.

The authors of this report are not aware of any work which has been carried out looking at marine energy-specific grid issues.

The development of grid capacity is driven primarily by the market, so the sort of long-term planning which supports the development of renewables can be more difficult to realise. The first grid connected pilot projects and marine energy farms in Chile will likely be built in areas which have available grid capacity (see map opposite and regional maps in Chapter 8). In the medium to long term however, access to suitable grid capacity will be a critical factor and investment in grid infrastructure will be required to fully realise Chile´s marine energy potential. A failure to plan for the long term development of the industry and make grid capacity available can delay developments, and inappropriate transmission charging mechanisms can affect the commercial viability of projects.



Case study 6-A: Electrical grid constraints in Scotland

The length of time and cost associated with connecting projects to the electricity grid has been a key barrier preventing renewable energy projects from coming online in the UK. Figure 32 shows:

- In blue – the forecast reduction in cost of energy from wave power (with uncertainty in lighter blue). Note that the cost reduction progress shown by this curve is dependent on an increase in cumulative device deployments, which are currently being held up by lack of grid access (shown on the x-axis).
- In orange – the component of the levelised cost of energy from wave arrays which it is estimated is a direct result of transmission charges.

These two points demonstrate how important it is to make sure that adequate access to the electricity is available and that charges to use this grid are appropriate. Also shown in green are two parameters related to the support mechanisms available in the UK - the required strike price for 20 year contracts and appropriate capital support to accelerate project development (in lighter green).

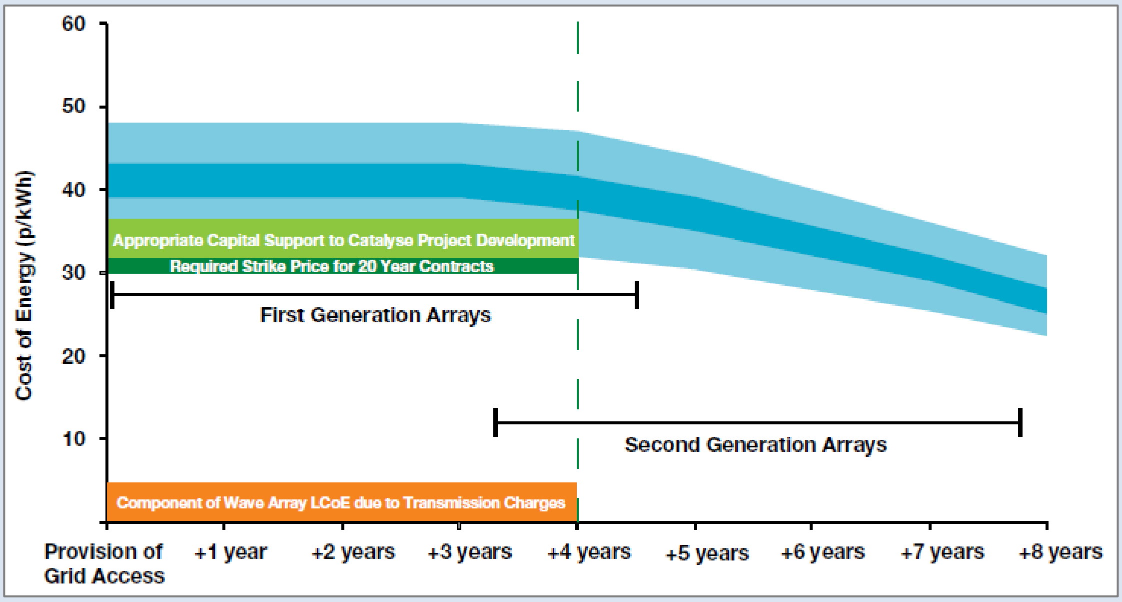


Figure 32: Anticipated levelised cost of energy for UK wave energy based on recent data submissions (Renewable UK, 2013)

Originally, grid connected arrays of marine energy devices were planned for 2015. Decisions to postpone grid investment now mean that this may be delayed to 2019 or even later. Scotland´s leadership position in marine energy is now being compromised by the lack of adequate access to the electricity grid which marine energy project developers are facing.

6.1.1 National and international connectivity

Chile´s electricity grid is made up of four separate networks, with 99% of the installed generation capacity situated in the Northern Interconnected System (SING) and Central Interconnected System (SIC), and the remaining 1% in Aysén and Magallanes. Generation in the SING is overwhelmingly from fossil fuel plants near the coast – see map in section 8.2, page 93. Around 90% of the power produced in that network is consumed by the mines. The SIC by comparison supplies 90% of Chile´s population with power and generation is split between hydroelectric (45%) and fossil fuel sources (55%), with smaller contributions from other renewables such as wind and biomass.

From the maps of the different regions of Chile in Chapter 8 it can be seen that a lack of grid connections in some areas has the potential to be a barrier to the integration of fluctuating renewable power sources in Chile. The Chilean Government does however have plans to connect the SIC and the SING by 2018.

6.1.2 Grid Capacity

Electricity grids in most countries have grown to connect large conventional power stations to centres of population and industry. As a result, the grid is strong between these centres but much weaker in peripheral areas where renewable energy resources are often found. The maps in Chapter 8 of this report include details of the capacity of many of the existing electricity lines and substations – see page 96 onwards.

Case study 6-B: Grid studies and connect and manage schemes (UK)

In the UK and Scotland in particular, much of the extractable wave and tidal energy is located in peripheral areas, and it was realised that long lead times for expanding transmission capacity could prevent the UK from meeting its 2020 renewable energy targets (see Figure 32). For this reason the UK´s Electricity Networks Strategy Group (ENSG) working group published a report in 2009 (revised in 2012) which set out the upgrades that might be required to ensure that sufficient renewable generation could be accommodated on the network (Electricity Networks Strategy Group, 2012).

The length of time and the cost of connecting to the grid has also been a key barrier preventing renewable energy projects from coming online in the UK. For this reason the UK Department of Energy and Climate Change (DECC) introduced a “Connect & Manage” scheme whereby generation projects are allowed to connect to the transmission system in advance of the completion of the wider transmission reinforcement work but are more closely managed until these wider works have been completed.

Chile may have an advantage over other countries such as the UK in that much of Chile´s power generation capacity and many of its population centres are strung out along the Pacific coast close to areas of high wave energy resource (see regional maps in Chapter 8). Furthermore, the two areas in Chile with significant tidal energy resource - the Chacao Channel and the Magellan Strait - have population centres relatively nearby (at Puerto Montt and Punta Arenas respectively). Nonetheless, carrying out a strategic analysis of the grid reinforcements which may be required to accommodate industrial scale marine energy developments could reduce risk and uncertainty.

Smart grid or “Renewable Power Zones” can allow the management of multiple renewable generators running on a grid network through the monitoring and controlling of power flows. Such an initiative has proved extremely successful in Orkney, UK and has allowed more than 20MW of additional capacity to be exported from the islands which were facing restrictions to transmission due to over capacity of firm connection. This type of initiative may be particularly relevant for areas such as Magallanes and Aysén where there is less available grid capacity.

Recommendation 6-A: Marine energy grid capacity studies (grid operators)

The Chilean grid operators **(CDEC-SIC, CDEC-SING, EDELAYSEN and EDELMAG)** in partnership with the **Ministry of Energy** and the **National Commission for Energy** may wish to consider commissioning studies similar to the UK´s ENSG study (Electricity Networks Strategy Group, 2012) which considers the grid upgrades that would be required to connect significant amounts of marine energy to the Chilean networks.

Chilean grid operators **Short to medium term**

6.1.3 Transmission Charges

In the UK, a significant barrier to the deployment of marine energy has been the high cost of transmission charges levied by the national grid operator on generators in northern and remote areas that are far from the centres of demand in the south. The Chilean Government has introduced partial or total exemptions for some NCRE projects connecting to core parts of the transmission network, but in other areas there are others which have been cancelled due to transmission costs rendering them unviable.

6.1.4 Electrical generation standards for generation devices

In addition to the grid "hardware", unique grid and power management skills and expertise will be required due to the nature of the power generated (Recommendation 6-B). The design of electrical systems for the grid connection of marine energy projects will depend on the installed capacity of the installation as well as the proximity and capacity of the local area network. In the UK, specific guidelines have been developed by the European Marine Energy Centre which reference existing regulations, codes and recommendations and provide specific guidance for the connection of marine energy projects to the national grid (EMEC, 2009).

6.1.5 Conclusions

Renewable energy projects can be delayed by inadequate or costly access to the electricity grid. Long term government planning can avoid these problems.

Studies focusing on the specific grid requirements of the marine energy industry can support a wider process of developing an electricity grid which is adequate for the energy sources of the future.

Recommendation 6-B: Marine energy grid studies (ICE)

The planned marine energy **ICE** may also be an appropriate organisation to study the electrical grid capacity requirements of marine energy in Chile. Other interesting focus areas could include:

- Reducing uncertainty around the grid connection requirements for marine energy projects;
- Reviewing the connection and transmission charges that marine energy projects are likely to face;
- Explore opportunities to guarantee early grid access for marine energy projects;
- Consider the potential for integration of marine energy projects with smart grids in remote areas, HVDC links from areas of high resource to electrical demand, pumped storage systems etc.;
- Review how grid upgrades for marine energy projects are planned for and funded, to make recommendations that support the sector´s development;
- Consider whether revision of existing grid connection guidelines is required to cater for wave and tidal power systems. Ref. Guidelines for Grid Connection of Marine Energy Conversion Systems (EMEC, 2009).

ICE **Short to medium term**

6.2 Maritime and industrial infrastructure

6.2.1 Introduction

The maritime and industrial infrastructure required to fabricate, install and maintain marine energy devices is similar to other offshore industries and includes:

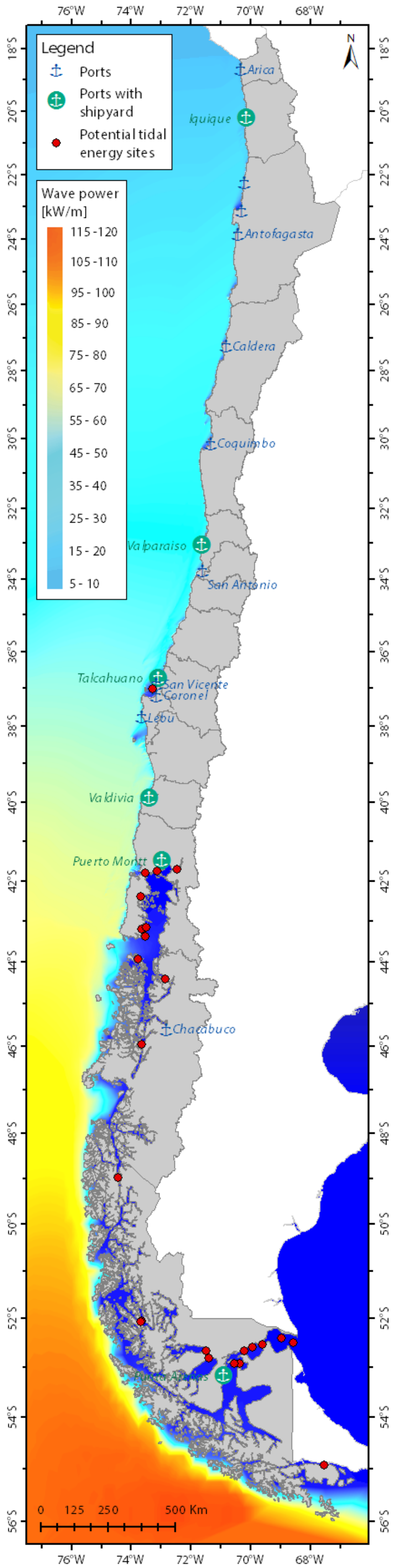
- Ports (with operation and maintenance base capacity)
- Vessels to install and maintain devices
- Access to raw materials
- Fabrication yards
- Lifting and transportation equipment

There are often specific requirements for marine energy projects however, driven by the size, weight and geometry of devices and the high energy operating environment.

Chile has a proud maritime history and considerable infrastructure with the potential for direct use or conversion to marine energy developments. The report *Preliminary Site Selection, Chilean Marine Energy Resource* (Garrad Hassan, 2009) identified the best locations for wave energy as being in proximity to key ports in Valparaiso, Bio Bio and Los Lagos regions, with Puerto Montt and Punta Arenas as the obvious support bases for large scale tidal projects in the Chacao Channel and Magellan Strait respectively.

The 2012 Marine Energy Development report (E&A/UoE) developed these ideas further, considering the economic benefits which could result from regenerating areas around San Vicente and Coronel, and highlighting the proximity of Chile´s steel industry in the Bio Bio region. *Note: This study considered only offshore wave projects, not near shore or onshore devices.*

Whilst the regions identified in these reports are certainly attractive, inspection of the maps in this report shows that opportunities for marine energy development do exist throughout Chile (see map opposite). In addition, the first sites to be developed in the short to medium term may not be the same as those that are most suitable for large deployments of mature technologies in the long term.



6.2.2 Infrastructure and supply chain planning

The Chilean Ministry of Energy plans to commission a study of the infrastructure, logistics and service requirements associated with the development of marine energy projects. The gaps in provision and barriers to development identified through this study should inform strategic development plans and support growth in local, regional and national supply chains.

Recommendation 6-C: Infrastructure and supply chain planning

Regional Governments in collaboration with the **Port Works Bureau** may wish to consider using the results of the planned marine energy infrastructure, logistics and services study to develop strategic development plans and stimulate growth in local supply chains. This work could ideally be coordinated with the international community to exchange knowledge and experience in key areas.

Regional Governments and Port Works Bureau | **Short to medium term**

Case study 6-C: Marine energy infrastructure planning (Scotland)

The marine energy industry in Scotland has benefited from the availability of an extensive existing network of maritime infrastructure (see Figure 33), support vessels and a skilled workforce that has built up around the North Sea oil and gas industry. Early decision making resulted in EMEC being established in Orkney, a maritime community with existing ports, electricity grid, support vessels and offshore expertise. This has meant that early technology prototype and full scale testing have not been significantly hindered by a lack of infrastructure or supply chain capacity. However, as the level of activity associated with technology testing and the build-out of the first demonstration sites and commercial-scale arrays increases, infrastructure and supply chain capacity is emerging as a key concern.

The Scottish Government - through its economic development providers (Scottish Enterprise (SE) and Highland and Islands Enterprise (HIE) - commissioned a report to develop a National Renewables Infrastructure Plan (N-RIP) which was completed in 2010. The purpose was to develop an investment strategy for port and infrastructure developments that would complement and enhance the renewable industry within Scotland. The motivation for developing this infrastructure stemmed from Scotland´s desire to become a European base for construction and assembly of wind turbines and marine devices.

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Case study 6 C: Marine energy infrastructure planning (Scotland)

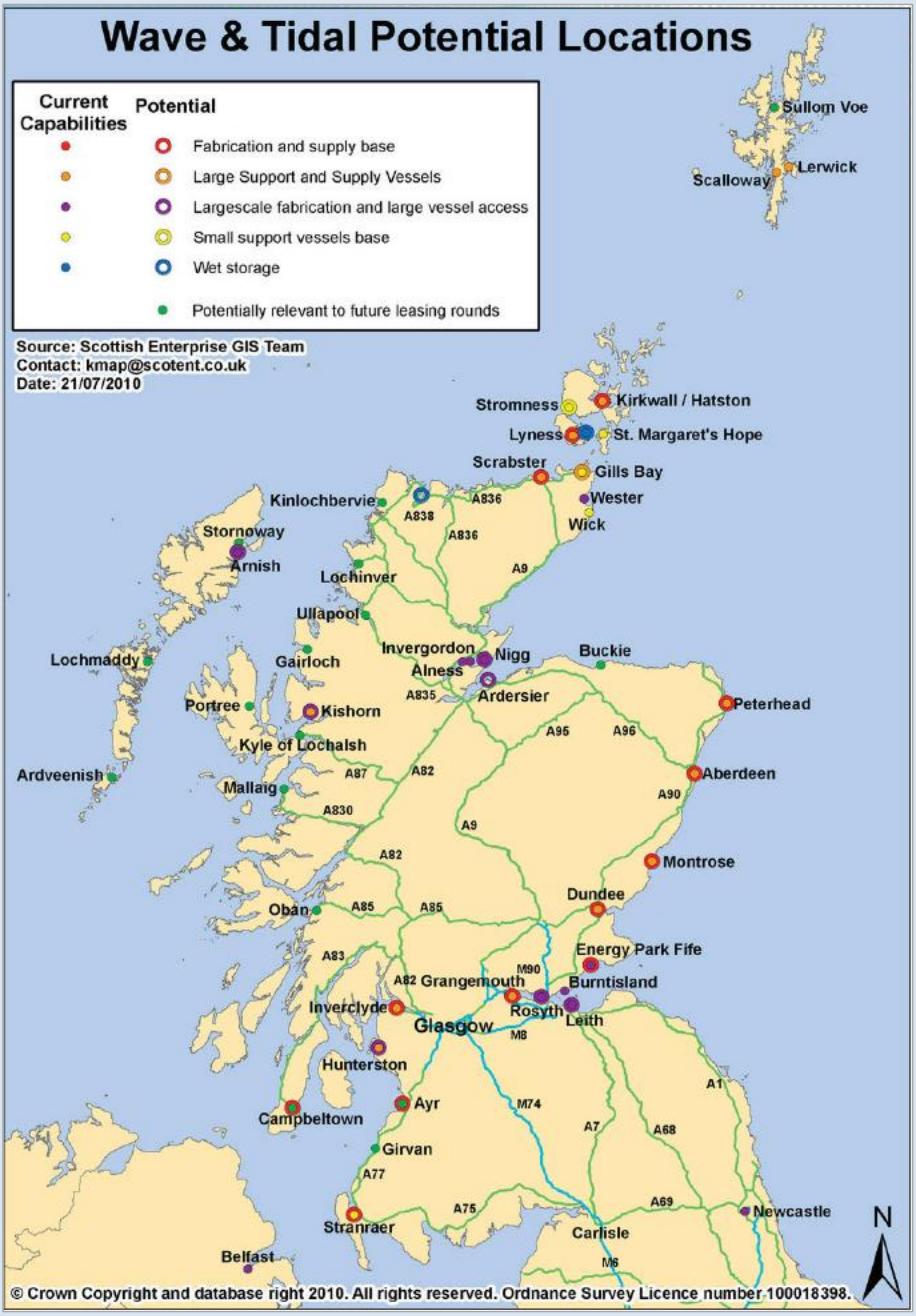


Figure 33: Evaluation of port capacity to support the marine energy industry (SE/HIE, 2010)

6.2.3 Support vessels

A particular challenge for Chile may be the availability of suitable vessels for installation, operations and maintenance purposes. Marine energy deployments in northern Europe have been made easier in some cases by the availability of dynamically positioned oil and gas industry vessels (see Figure 34), which were used (at a relatively high cost) for many of the earlier marine energy deployments.

Figure 34: Dynamic Positioning (DP) vessels deployed at EMEC’s tidal test site to install tidal turbines and support structures

Nonetheless, technology developers are now developing equipment and procedures to reduce the cost of installation by using standard vessels. Aquamarine Power, for example, installed the Oyster 1 device using a jack-up barge and shear-leg crane in 2009, but in 2011 the Oyster 800 was installed without a heavy lift, by ballasting it onto its foundations (see Figure 35).

Figure 35: Shear-leg crane barge and jack-up drilling during Aquamarine Power´s Oyster 1 Installation in 2009 (Left) and tug during self-ballasting Oyster 800 Installation in 2011 (Right)

Other examples include Pelamis who can deploy and recover their floating wave power device using a single Multi Category workboat, and OpenHydro who have used the same customised barge to install different versions of their tidal turbine (Figure 36).

Figure 36: Multi category workboats in Orkney (Left) and OpenHydro´s Installation Barge

Figure 37 demonstrates the high consistency of the Chilean wave regime compared with other sites. Whilst this implies a high potential for power generation, marine operations in Chilean waters will be more challenging as the opportunity to carry out activities during a period of reduced wave consistency (as for Orkney) does not exist.

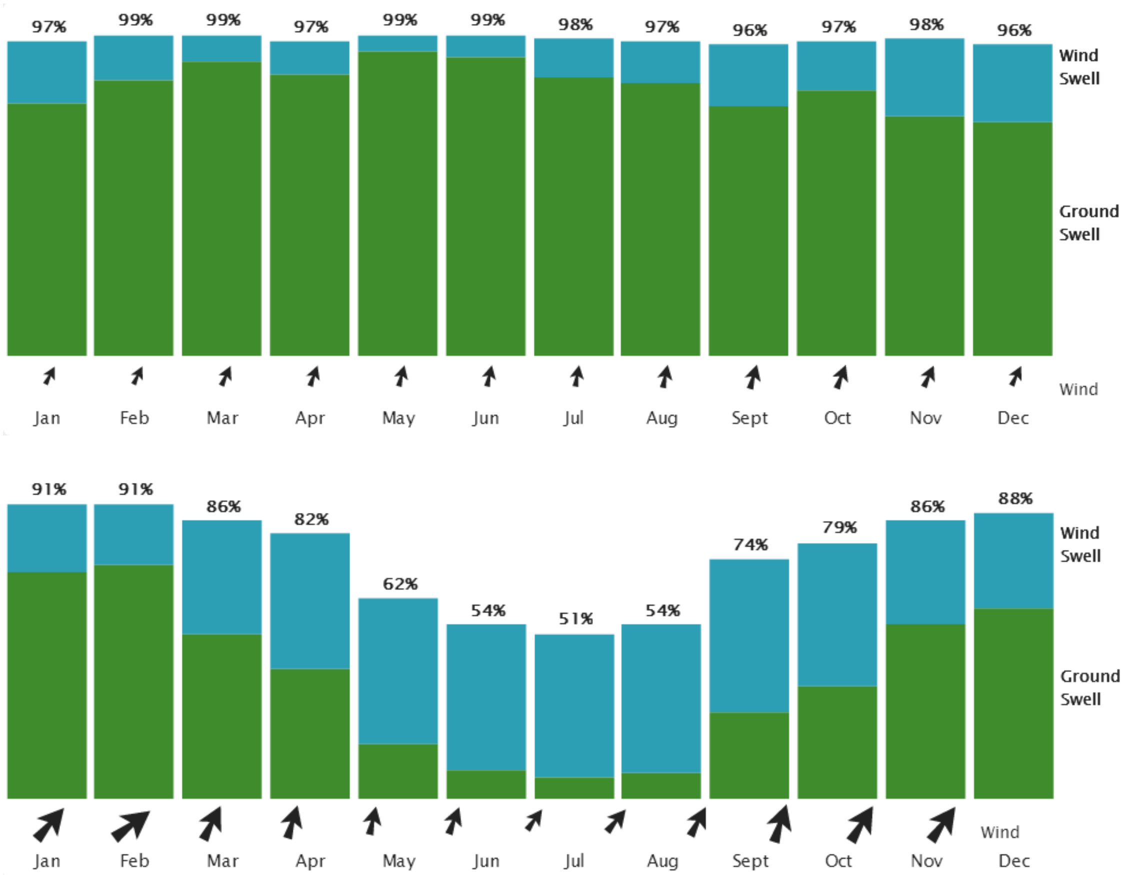


Figure 37: Comparison of swell consistency between Antofagasta, Chile (Top) and Orkney, UK (Bottom)[16]

Recommendation 6-D: Development of marine services

Vessel and marine service providers may wish to use the results of the planned marine energy infrastructure, logistics and services study to consider evaluating what equipment and methods will be required for marine energy developments in Chile, in order to inform their own strategies in the sector.

Vessel and marine service providers **Short to medium term**

6.2.4 Maritime marking and navigation

In Chile, the maritime marking service (*Servicio de Señalización Maritima*) controls and develops the national system of aids to navigation. This service is part of DIRECTEMAR, the general directorate of maritime territory and merchant marine of the Chilean Navy. The Chilean Navy have indicated that the marking of marine energy projects would be handled using existing norms for obstacles to navigation and the designation of special areas such as salmon farms (Chilean Navy, 2012).

[16] Consistency here is the percentage of time that the significant wave height is of 1m or greater. Wind swells are those with a mean period <7s; ground swells are those with a mean period of >7s. (MSW, 2013)

6.3 Supply chain

Beyond the major infrastructure needed to build, install and maintain marine energy devices, there is a web of services, equipment and minor infrastructure required throughout the life cycle of marine energy technology and project developments. There are however two very distinctive and different sets of supply chain needs between technology development and project development, as explored below.

6.3.1 Technology development

Over the last few years there has been a move within the marine energy sector to consider technology development in terms of Technology Readiness Levels (TRLs). These provide a standardised system for establishing progress along the technology development pathway. The United States Department of Energy (DOE) uses the following guidelines:

Table 9: Technology Readiness Levels (TRLs) - based on US Department of Energy method

Readiness Level	Description
TRL 1	**Scientific research begins translation to applied research and development** - Lowest level of technology readiness. Scientific research begins to be translated into applied research and development. Examples might include paper studies of a technology's basic properties.
TRL 2	**Invention begins** - Once basic principles are observed, practical applications can be invented. Applications are speculative and there may be no proof or detailed analysis to support assumptions. Examples limited to analytic studies.
TRL 3	**Active research and development initiated** - includes analytical studies and laboratory studies to physically validate analytical predictions of separate elements of the technology i.e. components not yet integrated or representative.
TRL 4	**Basic technological components are integrated** - Basic technological components are integrated to establish that the pieces will work together.
TRL 5	**Fidelity of breadboard technology improves significantly** - The basic technological components are integrated with reasonably realistic supporting elements so it can be tested in a simulated environment. Examples include "high fidelity" laboratory integration of components.
TRL 6	**Model/prototype is tested in relevant environment** - Representative model or prototype system, which is well beyond that of TRL 5, is tested in a relevant environment. Represents a major step up in a technology's demonstrated readiness. Examples include testing a prototype in a high-fidelity laboratory environment or in simulated operational environment.
TRL 7	**Prototype near or at planned operational system** - Represents a major step up from TRL 6, requiring demonstration of an actual system prototype in an operational environment.
TRL 8	**Technology is proven to work** - Actual technology completed and qualified through test and demonstration.
TRL 9	**Actual application of technology is in its final form** - Technology proven through successful operations.

The supply chain requirements at each of these stages of technology development are different. Whilst in general the requirements become greater as the technology develops, there are specific stages such as wave tank testing (TRL 4) or high capacity component testing (TRL 5) where these requirements can be more difficult to meet than at later stages. Examples of supply chain needs at each stage of technology development are outlined in Table 10.

Table 10: Examples of supply chain requirements at different stages of technology development

Marine energy technology development supply chain									
Technology Readiness Level (TRL) phase									
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
Key supply chain needs									
Stage	**Paper based process**	**Dry modelling**	**Wet laboratory component testing**	**Basic model testing**	**High capacity testing laboratory**	**Sheltered at sea test site**	**Full scale at sea demonstration through to commercial project**		
Facilities	Office	Office Lab	Office Lab	Office Lab Wave tank or tidal flume	Office Lab Wave tank, tidal flume or controlled test site	Office Lab Fabrication yard Test site and small support vessel(s)	See Figure 38 – project development supply chain requirements		
Skills	Scientific research	Basic design or analysis	Advanced design and analysis	Model building, testing and analysis	Engineering design and manufacture; testing and analysis	Eng. design and manufacture; testing and analysis; surveys; marine operations			

6.3.2 Project development

Project development requires that a technology has been successfully developed or that a parallel technology development process is being undertaken. Project development therefore corresponds to levels 8 and 9 (and to some extent, level 7) in the TRL sequence of activity, but has a much broader scope. The types of activity involved in project development are outlined in Figure 38

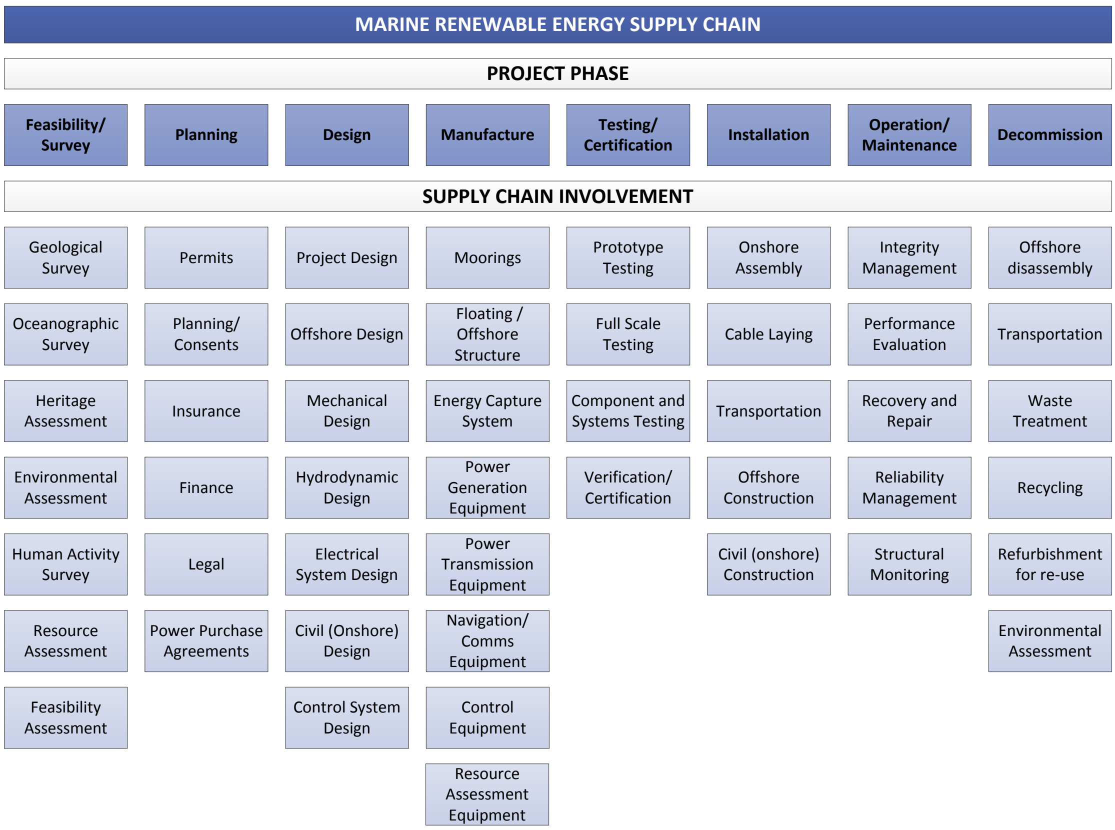


Figure 38 Project development supply chain requirements

- based on (Scottish Enterprise, 2005)

6.3.3 Trade and supporting organisations

Renewable and marine renewable energy associations and trade bodies can be influential in supporting industry development as well as in spreading knowledge about the sector. There are a number of such organisations already active in Chile.

Case study 6-D: Trade and supporting organisations (UK)

With the growth of renewables in the UK over the last 15 – 20 years, a number of trade organisations and representative bodies have become established. These organisations specialise in representing the industry to governments and policy makers. They also promote the industry running conferences and other media events. They are an important conduit for information, and their combined membership can be used as a lobbying tool. There are a range of these organisations and some examples which work in the marine renewable areas are described below:

Renewable UK - the largest UK wide trade organisation and is well resourced and supported. They run a number of events throughout the year which get a large attendance particularly at the annual conference (5,000 delegates, 300 exhibitors and 150 speakers).

Scottish Renewables -as a member organisation it covers similar areas to Renewables UK but with a Scottish focus. The website gives the description “SR are dedicated to strengthening business relationships and committed to securing the best possible environment for the growth of renewable energy in Scotland”.

There are also regional bodies such as Orkney Renewable Energy Forum (OREF), Shetland Renewable Forum (SRF), Northern Ireland Renewable Industry Group in Northern Ireland (NIRIG) and others which focus on the issues that affect the local areas.

Recommendation 6-E: Hold regular industry events; strengthen trade bodies/energy associations and expand these regionally

The renewable and marine renewable energy **associations** and **trade bodies** currently operating in Santiago may wish to consider encouraging the creation of regional or local branches, at least in those regions with most marine energy potential or current activity. Events such as an annual wave and tidal energy workshop and exhibition event could help promote the marine energy sector.

These organisations can often be well placed to stimulate supply chain development, and should be encouraged to link up with existing international counterparts so as to benefit from experience, strengthen international trade and encourage collaboration, etc.

Trade and supporting organisations **Ongoing**

6.4 Skills

Training and developing a workforce with the expertise and ability to make marine energy projects successful is an essential part of marine energy development. This section considers some marine energy training initiatives and their potential application to Chile.

Case study 6-E: The UK´s marine energy supply chain development

One of the key challenges identified in Renewable UK's report 'Marine Energy in the UK: State of the Industry Report 2012' was "developing a UK supply chain with the necessary skills and capacity to deliver rapid growth in the sector and to capture the socio-economic benefits of the industry in the long term".

The most recent available figure suggests that there are currently over 800 full-time equivalent jobs in the UK wave and tidal energy sector. The following pie chart (Figure 39) presents the breakdown by sub-sector. Future estimates predict that 7000 direct jobs (FREDS/MEG, 2004) could be created in Scotland within the marine energy industry, related to 1.3GW of deployment.

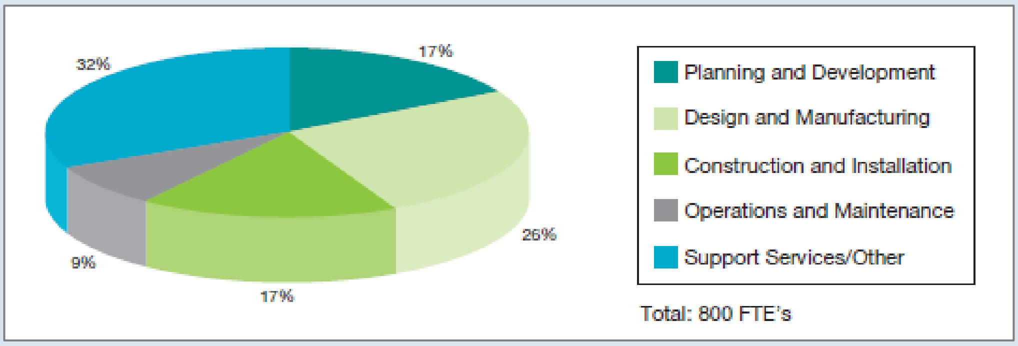


Figure 39: Direct UK Employment in Marine Energy (2010) (Renewable UK, 2011)

(Note: FTE = Full Time Employed)

Renewable UK's report on Employment and Skills in the UK Wind & Marine Industries (2011) reported that in the wave and tidal energy sector, 37% of employers reported that they had experienced difficulty in filling vacancies over the previous 12 months. These vacancies in the wave and tidal energy sector were mainly in specialist skills such as hydrodynamic modelling, aerodynamic mechanical engineering, hydrographic surveying, environmental consultancy, subsea design, ornithology and ecology. These skills may be transferable from other industries but often encouragement is needed to get workers to change industry. Chile is likely to face similar challenges once marine energy activity begins to increase.

Recommendation 6-F: Identification and resolution of skills gaps for the marine energy sector

The **Ministry of Energy** may wish to identify areas where supply chain training is required and to work in partnership with **Chile Valora** (Job skills certification committee), the **Ministry of Education** and the **Ministry of Labour**, to include these training requirements in their programs. The results of the planned infrastructure and services study could support this.

Various | **Medium term**

Case study 6-F: Academic marine energy courses in the UK

In the last few years a number or institutions have begun offering courses specifically aimed at marine/offshore renewables. Some of these are listed below:

Table 11: UK Institutions offering courses on marine/offshore energy

Institution	School	Course
Heriot-Watt University	Petroleum Engineering	Marine Renewable Energy
University of Strathclyde	Naval Architecture and Marine Engineering	Sustainable Engineering (Offshore Renewable Energy)
Robert Gordon University	School of Engineering	Offshore Renewables MSc
University of Exeter	Renewable Energy	Offshore Renewable Energy
Cranfield University	School of Applied Sciences	Offshore and Ocean Technology with studies in Offshore Renewable Energy
Plymouth University	School of Marine Science and Engineering	Marine Renewable Energy
University of Leeds	School of Electronic and Electrical Engineering	Electrical Engineering and Renewable Energy Systems
University of Edinburgh	School of Engineering	Marine Energy

Recommendation 6-G: Provision of renewable energy courses and training

Chilean Universities may wish to consider developing links with those institutions active in marine energy related course provision so that similar courses can be developed in Chile. **CONICYT** may wish to include such courses in their grant support programme. Such initiatives could also be part of a wider programme of support to train Chileans for other emerging renewable energy industries. Stronger links between industry and academic institutions will also help identify and address specific gaps.

Chilean Universities / CONICYT **Short term**

Case study 6-G: Low carbon employee training (Scotland)

In 2010 the Scottish Government announced an initiative to support employers who wish to develop their employees' skills in low carbon technologies. The 650 new places, to be delivered through Skills Development Scotland, are being funded with the support of the European Social Fund. The fund will enable employers to train employees in low carbon technologies as part of the Scottish Government's drive to maximise the economic benefits of greener business.

Case study 6-H: Marine energy training initiatives (European Union)

Several EU-funded training initiatives have been implemented in the past few years to tackle skills shortages, including:

- WAVETRAIN - Marie-Curie Research Training Networks. The project consisted of a total of 383 researcher-months contracted from outside each host institutions' countries, and a substantial amount of network wide training events with some focus on real sea testing. The main deliverables of the project are training of 15 young scientists in the field of wave energy.
- AquaRET - Vocational Training in Marine Renewable Energy Technologies. An EU project funded through the Irish National Agency under the Lifelong Learning Programme (Leonardo da Vinci - Transfer of Innovation). The main outcome was the development of online e-learning sessions within aquatic renewable energy technologies in order to inform the general public and stimulate companies to the aquatic renewable energy industry.
- In the UK, the Engineering and Physical Science Research Council (EPSRC) has funded the SuperGen Marine Energy Consortium to undertake collaborative marine energy research. An important aspect of the SuperGen Marine research programme is the inclusion of doctorates and training courses.

6.5 Conclusions – infrastructure and supply chain

The wave and tidal energy sectors are new and distinctive. As outlined above, although synergies may exist with existing activities, these new energy sectors will require specialist and dedicated support, depending on the size and stage of the market.

Experience has shown that existing companies will expand their activities to embrace marine energy. Indeed there are now a few service companies established which specialise in marine energy. For consultancy work these may be global, but for marine or technical services they are mostly local or regional for the moment.

It is often not recognised that a successful supporting supply chain may invest amounts similar to their customers in the building of new capacity. Such investments will not be made unless the supply chain is confident in an enduring market for their product or service. The immaturity of the marine energy sector and the financial status of many technology developers can create risks for the emerging supply chain. Deployments of tens of devices per year may be required in order for the sector to have the critical mass to support the supply chain.

7 Finance

Finance is a critical issue for the marine energy industry. Wave and tidal power technologies are in the early stages of development, and the current cost of energy from these sources - expressed as a levelised cost of electricity (LCOE) - is higher than many existing forms of energy production. Drawing universal conclusions beyond this is however difficult due to the variety of cost and revenue influences on marine energy projects and the nature of the various markets that require the renewable power that marine energy can supply.

7.1 Factors determining the financial viability of marine energy

Some of the key financial variables that need to be considered and some comments on their character are outlined in the tables below. These are presented separately for the wave and tidal sectors due to the significant differences between them.

Table 12: Factors determining the financial viability of wave energy

Factor	Description	Range or variability
Level of resource	Energy available from the waves at a particular point.	In Chile the annual average wave height varies from around 20kW/m in Arica to 110kW/m in Magallanes (Baird & Associates, 2012).
Amount of resource	Scale or area of a given resource which effectively means coastline length and extent of suitable seabed depths.	In steeply shelving areas there may be no suitable areas or only enough space for one line of wave energy devices. In other areas the strip of suitable seabed area may be 20-30km wide, allowing for multiple rows of devices. With energy extraction levels of around 5-10% per row of devices, it is assumed that three rows is a commercial limit, providing a capacity enhancement of almost three times the incident wave level.
Availability of the resource	The pattern in which the wave energy arrives at a particular point.	A constant level of wave activity gives higher output (higher capacity factors) and Chile has one of the most consistent wave regimes in the world (Monárdez, et al., 2008). Capacity factors in Chile may be around 50% as compared to around 30% in Europe. Periods of calmer conditions for accessing, installing, removing and moving devices may however be beneficial in cost terms.
Investment cost	The level of money invested in technology development which needs to be recovered from technology sales/ or operating revenue.	Some wave energy technology companies have already incurred costs in the region of 100million USD developing and testing MW scale devices and may need to spend 150million to 200million USD in total before they can deliver their first production machines in significant numbers. Later entrants to the market have managed to develop and test similarly-rated devices for much smaller sums of money (10-40million USD), although production performance against the early entrants has yet to be verified. Some companies are developing modular wave energy technologies at much lower cost, albeit at a scale of kWs rather than MWs capacity. Many of these technologies have been supported through grant aid and in some cases straight sales of early demonstration technology models. The residual levels of investment still to be repaid against future sales may therefore

		range from hundreds of thousands to tens of millions of dollars. Recovering these costs over for example the first 100 devices produced could therefore add thousands or hundreds of thousands of dollars to the individual device cost.
Technology capital cost (CAPEX)	The one-off costs of making and installing a device, or array of devices	Devices (or at least their structures) could be fabricated at lower cost in Chile, regardless of whether these technologies were developed in Chile or not. Installation of wave energy devices could be more expensive if large offshore construction vessels are required (as these may be more expensive to source than in Europe or the USA). Environmental conditions (waves/seabed slope) may be more challenging and therefore costly, but general vessel rates and staffing costs are lower.
Technology operation cost (OPEX)	The ongoing costs of operating and maintaining a device, or an array of devices.	Operation and maintenance may be more challenging due to the high consistency of the wave climate. Staffing costs are lower.
Project development cost	The one-off costs of identifying a site; obtaining permission to develop it; securing a connection to the market (grid or direct use) and a contract for the power produced.	There is very little experience of developing marine energy sites in Chile. Nonetheless it seems likely that the Chilean requirements may be less onerous than in many European countries where European Union directives can combine with national legislation to make the process more complex. The wave resource is distributed along all of Chile´s coast, so suitable sites should be easier to find as there are many interesting areas.
Track record value	The value associated with gaining experience for future projects.	Very high for wave power in Chile as the potential is vast.

Table 13: Factors determining the financial viability of tidal energy

Factor	**Description**	**Range or variability**
Level of resource	Energy available from the tides at a particular point	1.5m/s (3 knots) is often considered the minimum attractive level of mean spring peak tidal flow for commercial power production, although some designs (such as underwater kites) may be able to generate in less energetic conditions. Peak flows in the Chacao Channel or Magellan Strait can reach 4m/s (8 knots), a very attractive level of resource.
Amount of resource	Scale or area of a given resource which effectively means tidal channel depth, width and length.	Tidal energy by its nature is limited to specific channels and other flow constrictions (islands/headlands). There are a limited number of suitable sites available in Chile. The Chacao Channel and Magellan Strait are the largest but there are also many smaller sites.
Availability of the resource	The pattern in which the tidal energy fluctuates.	There is no available evidence to suggest that Chilean tidal flows have significantly different flow characteristics compared to other sites internationally. Tidal power is highly predictable but will drop to zero as the flow direction reverses (typically four times per day).
Investment cost	The level of money invested in technology development to be recovered from technology sales/ or	As for wave power, there are a number of tidal technology companies which have already incurred costs in the region of 100million USD developing and testing MW scale devices. These tidal power technologies are closer to being

	operating revenue	commercialised than for wave power. There are also some second generation device developers who have managed to make comparable levels of technological progress with much lower investments – particularly the developers of small scale devices. The residual levels of investment still to be repaid against future sales, as for wave, may therefore range from hundreds of thousands to tens of millions of dollars. Recovering these costs over say the first 100 devices produced could therefore add thousands or hundreds of thousands of dollars to the individual device cost.
Technology capital cost (CAPEX)	The one-off costs of making and installing a device, or array of devices	Tidal energy is more advanced than wave and therefore it will be more difficult for Chile to play an active role in technology development. The structures and/or foundations of the devices could however be manufactured in Chile at lower cost than elsewhere.
Technology operation cost (OPEX)	The ongoing costs of operating and maintaining a device, or an array of devices.	Operational costs should be lower in Chile because many of the tidal sites are relatively benign (low waves/ice/debris). Assuming the use of large offshore construction vessels can be minimised, vessel and manpower costs will also be lower.
Project development cost	The one-off costs of identifying a site; obtaining permission to develop it; securing a connection to the market (grid or direct use) and a contract for the power produced.	There are a limited number of potential tidal power sites in Chile, and almost all of those that do exist are in Los Lagos, Aysén and Magallanes. This limited pool of sites and the high value placed on the environment in these areas has the potential to increase project development costs. In Aysén and Magallanes the local grid operators do not have the same renewable energy targets or obligation to connect renewable energy generators that exist in the SIC and SING.
Track record value	The value associated with gaining experience for future projects.	Moderate for tidal power in Chile as the number of sites is limited.

Table 14: Technology-neutral considerations

Factor	Description	Range or variability
Revenue	The amount of money that can be made on the energy supplied from wave or tidal power devices.	No generation subsidy exists. Wave and tidal must compete with other forms of NCRE. Electricity prices in Chile are high however, particularly in remote areas dependent on diesel generation.
Tax *Source:* (PWC, 2008)	Tax liabilities	Domestic Entities resident or domiciled in Chile are taxed upon their worldwide income (exception where double taxation agreements apply, of which Chile has many). Individual tax: progressive from 0% to 40% Corporate tax: 17% (“First Category Tax”) Value added tax: 19%. International General services subject to Additional Tax at 35%. Technical and engineering services taxed at a 15% rate withholding tax (20% for related parties). Various double taxation agreements exist.

7.2 Markets for wave and tidal power in Chile

This section evaluates the different markets available for wave and tidal power in Chile:

- Large electricity networks (SIC and SING)
- Medium sized electricity networks (Aysén and Magallanes)
- Off-grid projects

7.2.1 Large electricity networks (SIC and SING)

The wholesale power market in Chile in the SIC and SING operates on a principle of competitive generation at lowest cost, with two markets: a spot market, with prices determined on the basis of Short Run Marginal Costs (SRMC), and a bilateral contracts market. Generators therefore have the following options for selling their electricity:

1. Spot market (at SRMC)
2. Long term contracts with other generators or large consumers at non-regulated prices
3. Long term contracts with distributors, established via competitive bids

7.2.1.1 Spot market

Prices on the spot market consist of:

1. The system SRMC is set on an hourly basis by the Dispatch operator (CDEC-SING or CDEC-SIC). The SRMC is calculated for each node of the system. All transactions between generators and the spot market are carried out at this price.
2. The capacity price, set every 6 months by the regulator on the basis of annualised capital cost plus operation and maintenance costs for a reference efficient open-cycle gas power plant. Generators have to buy or sell the difference between their "firm capacity" and the expected maximum demand under their contract commitments at the capacity price. Repayments for any deviations between projections and real demand and supply are made at the end of the year.

Spot prices in Chile are amongst the highest in Latin America and exhibit a high degree of volatility. One reason for this is the unstable output from hydroelectric plants located in the SIC. In periods of drought, more expensive thermal plants such as diesel are used to compensate for the lack of water. Commodity price fluctuations have a large impact on Chilean electricity prices. For example, average spot prices rose by 64% between Q1 2010 and Q1 2011 (from 149 to 244 USD/MWh) due to a combination of severe drought and high commodity prices. Gas supply restrictions from Argentina have been a major contribution to these high and volatile spot prices, which reached a peak of almost 350 USD/MWh in March 2008 at the height of the gas crisis. In general, 70-80% of generators' revenue comes from participation in the spot market; the remaining 20-30% is made up from sale of firm capacity.

7.2.1.2 Contracts market

Prior to the Short Law II of May 2005, contracts with distributors were set at node prices, which were set by the energy regulator (CNE) every 6 months. Node prices consisted of 2 components – energy node price, calculated based on expected SRMC, and capacity node price, corresponding to the capital and O&M cost of a reference gas turbine. The calculated node price (capacity + energy) had to be adjusted in order to fit in -5% to +30% of the average price agreed between generators and consumers in the unregulated market.

As of January 2010, the supply price to distributors is established through competitive bids, where each distributor announces its energy and capacity requirements and generators offer the lowest price for the contracts they want, with contract terms set at 15 years. Old outstanding contracts were priced at node prices.

7.2.2 Medium sized electricity networks (Aysén and Magallanes)

The electricity networks of Aysén and Magallanes are classed as “medium size electricity networks” and are not subject to the same renewable energy (NCRE) targets or regulations as regards the inclusion of additional generators to the grid. In these areas, unlike in the SIC and SING, the functions of generation, transmission and distribution are controlled by single entities (EDELAYSEN and EDELMAG).

7.2.3 Direct supply to industrial clients

There are many coastal industries in Chile that could be supplied directly with power generated from wave or tidal power devices. Many ports, mining export terminals, desalination and water pumping or treatment plants (and almost all salmon farms) have their own generators on site. There is the potential for marine energy to replace or reduce conventional generation for these clients. In wind and solar this is already happening, for example in Magallanes where wind turbines were erected to provide electricity for a methanol plant on the outskirts of Punta Arenas.

Such projects could take the form of bilateral contracts at non-regulated prices (see 7.2.1 above), but others could involve industrial clients not connected to the grid or who own the power generation equipment themselves.

7.2.4 Isolated communities

Chile has many communities which are isolated from access to the electricity grid or fresh water by distance or difficult terrain. These areas generally have higher energy costs than in the main electrical systems (see costs of diesel generation in remote areas Figure 43). It is also worth noting that projects of less than 3MW do not need to pass through environmental impact evaluation (SEA). As described in the RD&I and regional chapters of this report, there is a significant opportunity for wave and tidal power to supply power and water to isolated communities in Chile and indeed for these projects to be community owned.

7.3 Currently available support

Until marine energy can compete directly with other forms of generation, early projects will require support – both capital grants and possibly revenue support - for technology development (research and development) and for the first ocean energy farms until such time as the technology cost has reduced to a level where it is competitive with other forms of energy.

The Ministry of Energy´s draft Marine Energy Strategy sets out ambitions to deliver instruments which support and promote investment and development of a marine energy industry in Chile. It acknowledges that the project finance model is a difficult option and that the possibility of some form of subsidy should be explored, in addition to financial support instruments targeted at barriers to market entry.

The Chilean electricity market is deregulated and operates on a lowest cost model. Incentives and targets for Non-Conventional Renewable Energy (NCRE)[17] do exist (and have recently been increased); however, these are currently technology-neutral and not aimed at pre-commercial technologies such as wave and tidal.

The 2011 Marine Energy Development report (E&A/UoE, 2012) presented incentives and project finance tools for developing marine energy, based on European and specifically UK experience. For a Chilean marine energy development strategy (which is what the Chilean Government has stated it wished to pursue), various potential support mechanisms were discussed including the UK ROC system, the auctions implemented in Peru and Brazil, and feed-in tariffs in Canada.

It is worth noting the different tax exemptions and free trade zones in Chile which can have a significant positive impact on project economics. These are shown in Figure 40.

DFL 15. Regions of Arica and Parinacota; Tarapacá; Aysén del General Carlos Ibañez del Campo; Magallanes y Antártica Chilena; and Chiloé and Palena provinces (from Los Lagos Region): 20% allowance for investment in fixed assets for projects less than or equal to US$ 1.4 million dollars, and sales of up to US$ 1 million dollars.

Arica Plan. First Category Tax Exemption up to: 30% (investment in fixed assets) in Arica province; 40% (investment in construction and real state property) in Parinacota province; 40% (investment in property intended to tourism projects) in Arica province. All of them from the **Arica and Parinacota Region.**

Austral Plan. Regions of Aysén del General Carlos Ibañez del Campo; Magallanes and Antártica Chilena; and Palena province from Los Lagos Region: First Category Tax Exemption up to 32% of the investment in fixed assets.

Laws Navarino and Tierra del Fuego. 20% allowance over net sales (within the country); and First Category Tax Exemption (until 2035) respectively, in Porvenir and Primavera provinces, both from Magallanes and Antártica Chilena Region.

DL 889. Regions of Arica and Parinacota; Tarapacá; Aysén del General Carlos Ibañez del Campo; Magallanes y Antártica Chilena; and Chiloé and Palena provinces (from Los Lagos Region): Human Resource Bonus 17% minimum wage per person.

FREE TRADE ZONE. Tax benefit on purchases over fix assets in **Arica and Parinacota Region and Tarapacá Region .**

Figure 40: Chilean tax exemption and free trade zones (InvestChile CORFO, 2011)

Various financial support instruments for renewable energy projects are already available in Chile, and the majority of these are administered by CORFO, the Chilean Government´s economic development agency. The main financial support mechanisms which could potentially be used to support marine energy projects are presented in Figure 41.

[17] Defined by the Chilean Government as excluding large hydroelectric projects

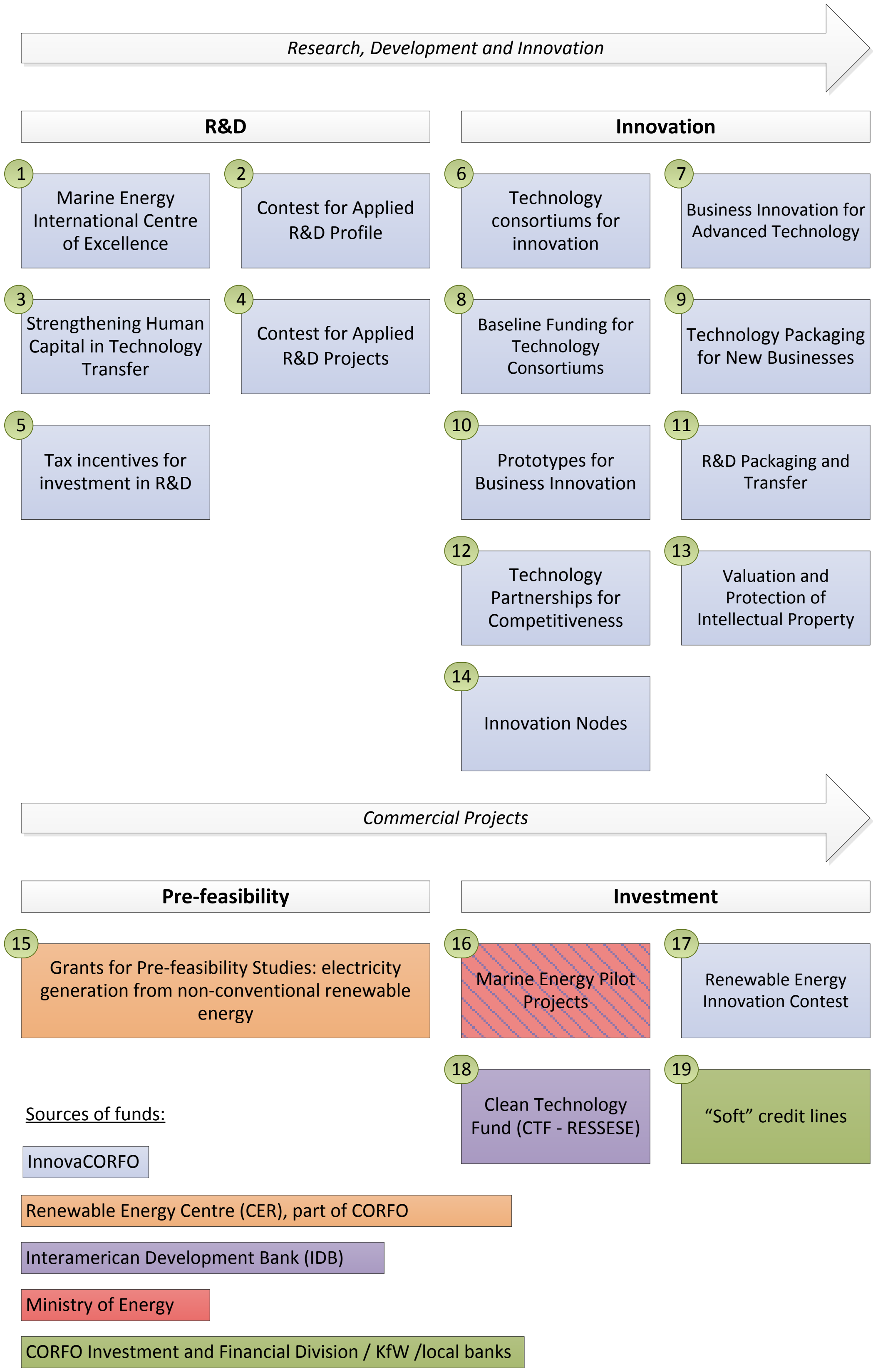


Figure 41: Financial support mechanisms available in Chile with the potential to be applied to marine energy projects (see website links below)

Website links for each of the funds in Figure 41 are presented below:

1. **http://www.corfo.cl/programas-y-concursos/programas/atraccion-de-centros-de-excelencia-internacional-de-id-en-energia-de-los-mares**
2. **http://corfo.cl/programas-y-concursos/programas/concurso-perfil-de-id-aplicada**
3. **http://corfo.cl/programas-y-concursos/programas/concurso-fortalecimiento-de-capital-humano-en-transferencia-tecnologica**
4. **http://corfo.cl/programas-y-concursos/programas/concurso-proyecto-de-id-aplicada**
5. **http://corfo.cl/programas-y-concursos/programas/incentivo-tributario-a-la-inversion-privada-en-investigacion-y-desarrollo**
6. **http://corfo.cl/programas-y-concursos/programas/consorcios-tecnologicos-para-la-innovacion**
7. **http://corfo.cl/programas-y-concursos/programas/programa-de-innovacion-empresarial-de-alta-tecnologia**
8. **http://corfo.cl/programas-y-concursos/programas/financiamiento-basal-transitorio-para-consorcios-tecnologicos**
9. **http://corfo.cl/programas-y-concursos/programas/empaquetamiento-tecnologico-para-nuevos-negocios**
10. **http://corfo.cl/programas-y-concursos/programas/prototipos-de-innovacion-empresarial**
11. **http://corfo.cl/programas-y-concursos/programas/concurso-empaquetamiento-y-transferencia-de-id**
12. **http://corfo.cl/programas-y-concursos/programas/asociaciones-tecnologicas-para-la-competitividad**
13. **http://corfo.cl/programas-y-concursos/programas/valorizacion-y-proteccion-de-propiedad-intelectual**
14. **http://corfo.cl/programas-y-concursos/programas/nodos-para-la-innovacion**
15. **http://cer.gob.cl/concurso-preinversion/**
16. **http://www.iadb.org/es/proyectos/project-information-page,1303.html?id=CH-G1002**
17. **http://corfo.cl/programas-y-concursos/programas/concurso-de-innovacion-en-energias-renovables**
18. **http://www.iadb.org/en/projects/project-description-title,1303.html?id=CH-T1132**
19. **http://www.corfo.cl/programas-y-concursos**

7.4 Industry needs

It can be seen from Figure 41 that there are a significant number of funds available for RD&I projects in Chile. A number of Chilean technology developers and universities have already been taking advantage of these funds to advance small scale projects (see examples in Figure 42). The Renewable Energy Centre´s funds for prefeasibility studies can be used to evaluate marine energy projects, and there has been some private sector interest in using CORFO´s innovation consortium fund to realise marine energy projects. The Clean Technology, KfW and Renewable Energy Innovation funds however are all designed for more mature technologies with more competitive energy costs and lower technology risk.

Whilst some of these funds may be useful as part of a wider financing arrangement, the two instruments with the potential to make a significant impact on marine energy in Chile in the short term are the pilot projects and the International Centre of Excellence (ICE) program.

The proposed marine energy pilot projects aim to install the first large scale marine energy devices in Chilean waters. The total support available is understood to be 9m USD for tidal and 5m USD for wave, with these amounts funding 50% of the project costs. Bids are expected to be invited during 2014 and the aim is to have devices in the water by 2016. The fund will be administrated by the Ministry of Energy, with support from the Inter-American Development Bank, who are to provide some additional funds for the pilot projects.

The planned marine energy ICE would carry out applied research, development and innovation which support the development of the Chilean marine energy industry. The maximum grant amount available is understood to be 13m USD, spread over 8 years and with 7m USD required in match funding. Half of this match funding can be non-financial (in-kind) contributions. The fund will be administrated jointly by InnovaCORFO and the Ministry of Energy.

Since 2008 Chile has had a tax credit of 35% for expenditures on research and development contracts. In 2012 a new law was passed which tripled the amount of tax credit available to each company to 1.2million USD; included a wider variety of expenditures; made procedures more flexible; allowed claims to be made up to 180 days after the work started, and removing a gross sales percentage ceiling to allow start-ups and SMEs to use the credit. Significantly for international companies, up to 50% of research and development activity which takes place outside of Chile can also now be claimed.

Existing funds have been sufficient to support some Chilean companies to test small or part-scale prototypes (see Figure 42) as well as to various university projects and other studies. The pilot projects will ensure Chile´s first full-scale at sea deployments and the centre of excellence will maintain a level of RD&I activity – the following section of this chapter considers the path to commercialisation of the industry, and the support that may be required in the interim.

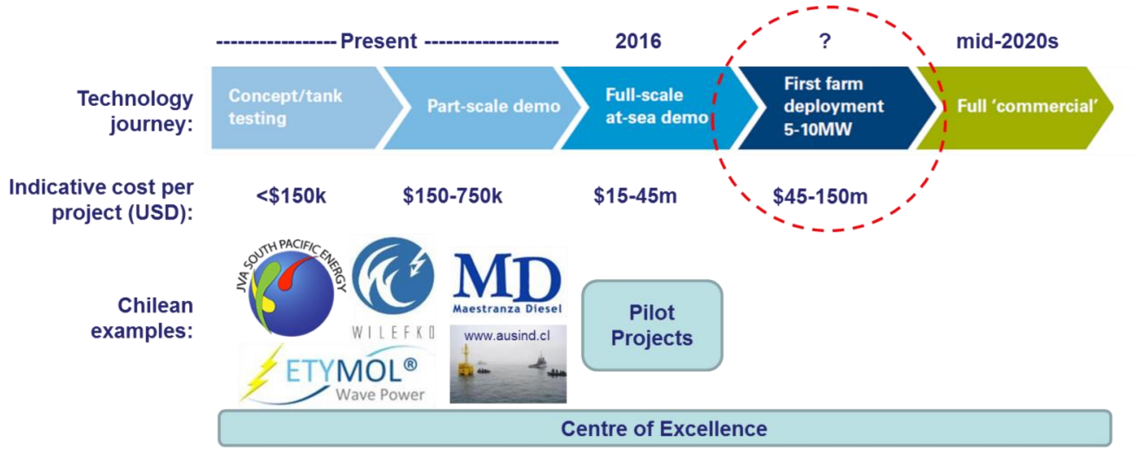


Figure 42: Technology journey - based on (Carbon Trust, 2011)

In the 2011 report *Accelerating Marine Energy* (Carbon Trust, 2011) the UK Carbon Trust made forecasts on the likely pace of marine energy cost reduction with global installed capacity. Figure 43 compares these figures to historic Chilean grid electricity prices and the historic and forecast cost of diesel generation. It should be noted that smaller projects would not achieve the economies of scale inherent in the Carbon Trust calculations for industrial marine energy deployments. However given the rising cost of diesel generation, the potential for marine (and particularly tidal) energy to compete with diesel generation is increasingly attractive.

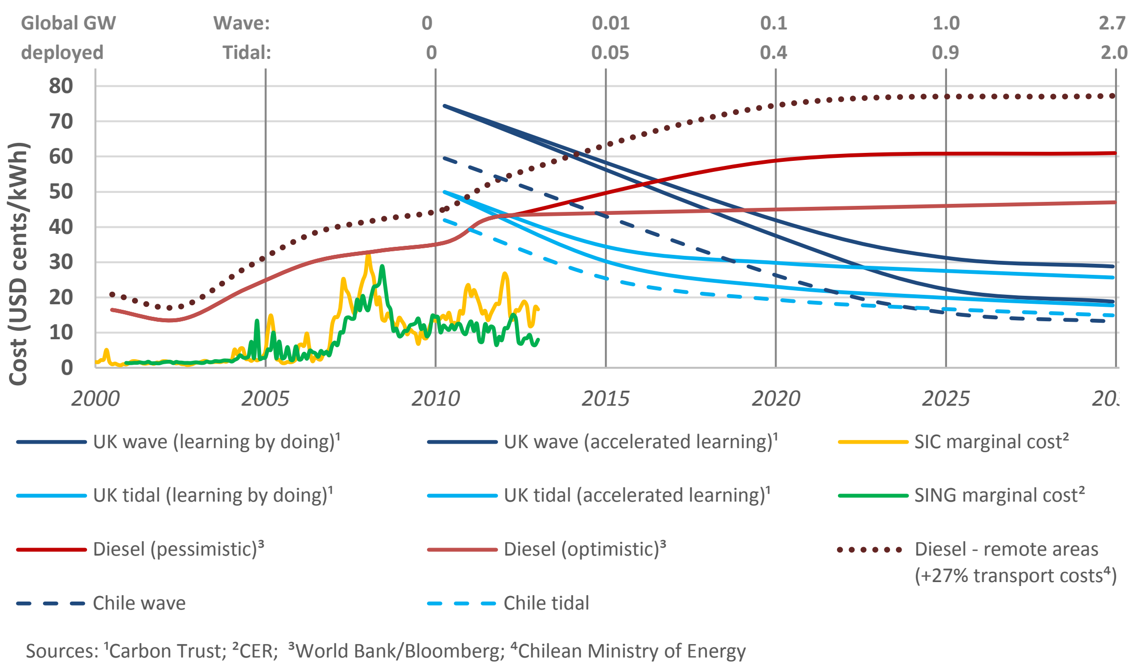


Figure 43: Chilean electricity spot market prices compared to the levelised cost of diesel, wave and tidal power generation

Note: levelised cost of energy forecasts for wave and tidal shown in dark and light blue on Figure 43 depend on global deployment of marine energy (upper x-axis), rather than the year (lower x-axis).

For the reasons given previously in sections 7.1and 0 and based on a provisional LCOE analysis carried out by Aquatera, it is believed that reductions in levelised cost of up to 16% for tidal and 30% for wave may be achievable in Chile (see Figure 43). It would be beneficial to confirm these estimates with more detailed work (Recommendation 5-B, page 41).

Although the interconnection of the SIC and SING systems in 2018 may bring electricity prices down for a time, the likelihood is that in the longer term Chilean electricity prices will continue to rise as a result of increased demand and continued dependence on foreign fossil fuel imports.

The levelised costs of wave and tidal power will fall as the cumulative output from these sources rises. At what point grid-connected utility scale projects may become commercial remains uncertain, but it seems possible that some projects could be cost-competitive with other forms of renewable energy by the mid-2020s.

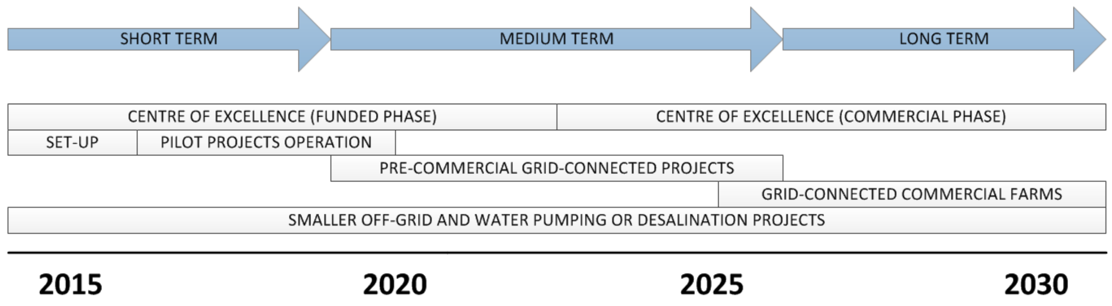


Figure 44: Potential development scenario for marine energy in Chile

Figure 44 shows a potential development scenario for marine energy in Chile. Financial support sufficient to realise the pilot projects and centre of excellence activities has been announced by the Chilean Government. This is an excellent first step on the road to commercial utility-scale projects and will guarantee a certain amount of marine energy activity in the short term, but is unlikely to maintain a significant level of marine activity to the point of commercialisation.

In the medium term (see Figure 44) it is not clear how any pre-commercial projects would be financed prior to 2025 at the earliest. With the financial support mechanisms currently available there is a risk that Chile´s marine energy industry will lose momentum, as there is the potential for a gap in installation activity between the end of the part-funded operational phase of the pilot projects and the onset of commercially viable projects.

Case study 7-A: Financial support for marine energy projects (Europe)

In Europe, industrial and utility investors have already invested hundreds of millions of (US) dollars in the marine energy sector. It is now widely acknowledged that a unified approach is required to manage the three major categories of technical, project and financial/market-based risk. This would require substantial commitment, both at a state and European level, estimated at around €1 billion. On the financial side, financing and project development will require technology push support (grants) to reduce technology risk and market pull (revenue support) to deliver competitiveness. The European Ocean Energy Association has highlighted the need to encourage private sector investment through revenue support in the early years allied to soft loans, co-investment and public guarantees, in order to de-risk project finance.

It is no coincidence that most commercial marine energy technology development is centred on the UK, where the latest proposed UK tariff is £305 per MWh for projects commencing by 2017 (this is almost 50 US dollar cents per kWh, ref. Figure 43). Substantial financial support is also available in France and is closely linked to projects resulting in direct industrial activity within that country. Nova Scotia in Canada has recently set an initial tariff of 575 USD per MWh for test devices at the Fundy Ocean Research Centre for Energy.[18] It should also be noted that the total cost to date of the world-leading Renewable Obligation in Scotland has been less than 75,000 USD (because of the relatively low amount of power produced to date) yet this measure has been instrumental in bringing record-breaking numbers of marine energy companies to Scotland and the UK.

[18] http://thechronicleherald.ca/business/1167128-tidal-energy-payment-rates-set

7.5 Conclusions – finance

Based on the results of the research and consultation carried out as part of this project, the possibility of a technology specific market-pull or generation incentive such as a feed-in tariff or ROC system being introduced for marine energy in Chile is remote, certainly in the short term at least. Some argue that it would be in fact be unconstitutional for the Chilean Government to intervene in the market in this way.

A more likely scenario could be for Chile to introduce an auction or invitation to bid for a modest block of marine energy (say 10 to 30MW) in the medium term - perhaps through an expansion of the pilot projects around the year 2020. As outlined in the Errazuriz & Associates/University of Edinburgh report, such a measure must be carefully designed to develop the marine energy supply chain in Chile through the use of local materials, goods and services.

An expansion of the pilot projects towards the end of this decade would help maintain momentum in the industry before the advent of commercial farms, but would not be sufficient for Chile to play a significant role in the sort of “learning by doing” cost reduction activity associated with the deployment of hundreds of MWs and described by the Carbon Trust in the RD&I section of this report (page 37).

It may still be possible for Chile to pursue a development strategy without subsidising large scale pre-commercial deployments, in particular by:

- Maintaining some activity in the conventional area of large scale grid connected prototypes through the development of a new funding instrument to support the first pre-commercial farms in Chile. For example, this could involve an expansion of the planned wave and tidal pilot projects (which will likely total <2MW installed capacity) to include multiple devices (say 10 to 30MW capacity) in the medium term e.g. around 2020.
- Supporting RD&I projects which contribute to reducing technology risk and bringing costs down to commercially viable levels. This work must be coordinated with the needs of the global marine energy industry: there are already examples of marine energy RD&I taking place in Chile for devices deployed abroad, and the adaptation of such machines for Chilean water is likely to be a key focus. This must however be considered alongside supporting the development of Chilean technology.
- Developing new studies and funding instruments to support the development of niche markets where Chile has a natural advantage, for example:
    - Wave-powered desalination and water pumping in the north of Chile:
        - Large scale - for the mining industry and population centres
        - Small scale - for isolated communities
    - Small scale wave-powered electricity generation for isolated communities.
    - Small scale tidal-powered electricity generation for isolated communities and salmon farms in the south of Chile.

Across mining, salmon, shipbuilding and other key industries there are opportunities for private companies to form alliances to develop marine energy RD&I which will bring strategic advantages in the longer term. Some of the funds shown in Figure 42 (such as the fund for technology consortiums) would be sufficient to realise marine energy projects if private companies (or consortiums of them) are willing to make strategic investments.

Recommendation 7-A: Financial support for off-grid marine energy projects

The **Ministry of Energy** and **CER** in partnership with **Regional Governments** may wish to consider developing financial support instruments to support the development of small scale, off-grid marine energy projects for the supply of power or fresh water to isolated communities and specific industries such as aquaculture. This could include feasibility studies, pilot projects and related research.

These types of project can be implemented at relatively low capital cost, so a focus on projects of this scale is a cost effective (and relatively low-risk) way to maintain momentum within the marine energy industry in Chile. This could be particularly important if the levels of financial support necessary for larger projects do not materialise.

This area has received comparatively little support to date internationally, but some local Chilean **technology developers** and **researchers** are already making progress on this front. Given the relative lack of support for these types of projects in other countries there is significant potential for international export of technology and skills if Chile becomes a leader in this area.

Chilean Government **Short term**

Recommendation 7-B: Financial support for wave-powered desalination and water pumping projects

The **Ministry of Energy** and **CER** in partnership with the **Ministry of Mining** may wish to consider developing a financial support instrument to encourage studies and projects on wave-powered water pumping and desalination for the mining industry. This could include feasibility studies, pilot projects and related research.

The market for these types of projects in Chile is very large and as this area has received comparatively little support to date internationally. This may be a more appropriate focus than the conventional area of grid-connected (electricity-generating) wave energy devices.

Chilean Government **Medium term**

Recommendation 7-C: New financial support instrument for 10-30MW expansion of pilot projects by 2020

The **Chilean Government** may wish to consider introducing an auction or invitation to bid for a block of marine energy (for example 10 to 30MW) in the medium term (perhaps by 2020) in order to support the first pre-commercial farm(s) of wave and tidal energy devices in Chile.

This would help maintain the level of marine energy activity in the country until large scale projects become commercially viable, and would help ensure Chile continues to take an active role in marine energy development.

Such projects could be either grid-connected or supplying some other energy market (e.g. direct electrical client, desalination or water pumping, etc.).

Chilean Government **Medium term**

8 Regional analysis

8.1 Introduction

Chile is a vast country, stretching over 4,000km from desert in the north to glaciers in the south. Some of Chile´s fifteen regions are of comparable size to many countries, so marine energy policy must take this extensive and diverse geography into account.

This chapter of the report explores the marine energy potential of the different regions of Chile. Opportunities and challenges are evaluated and regional priorities proposed. For the purpose of this report Chile has been divided into seven marine energy regions, all with their own distinctive distinct natural and built environments. As shown in Figure 45, these marine energy regions consist of multiple administrative regions.

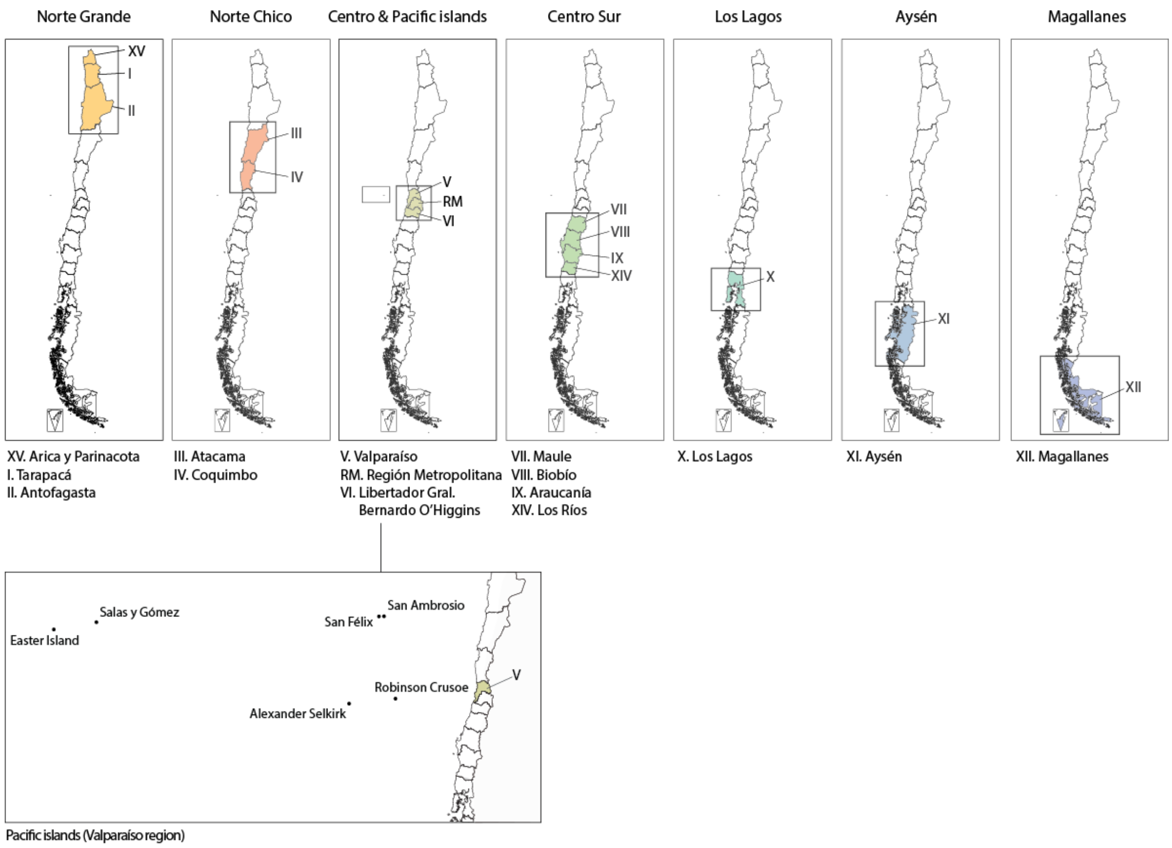


Figure 45: Marine energy regions evaluated in this report

Mainland Chile spans 39 degrees of latitude, from 17°S on the border with Bolivia and Peru to 54°S at Cape Froward in Patagonia. The difference in climate between the northern and southern most extremes of the territory results in different patterns of energy production and use as well as in fresh water availability.

Many of Chile's most densely populated areas are found on or near the coast, and space for energy generation projects in developed areas can be limited. More than half of Chile's population and most of the country´s economic activity are found in the central zone (Table 15). Elsewhere, there are large tracts of land with low population density and many isolated communities.

Table 15: Economic data for the different regions of Chile

Marine energy region	Administrative region	Population[19]	% Share of National GDP[20]	GDP per capita (PPP)[21]	% Unemployment rate[22]	% Poverty rate[23]
Norte Grande	XV. Arica y Parinacota	181,402	0.63	7,096	7.5	17.8
	I. Tarapacá	328,921	2.47	15,359	4.4	15
	II. Antofagasta	588,130	10.50	36,549	5.4	9.1
Norte Chico	III. Atacama	284,607	2.75	19,762	5.0	15.8
	IV. Coquimbo	739,153	3.20	8,866	6.3	17.5
Centro	V. Valparaíso	1,795,765	8.07	9,196	7.5	20.3
	RM. Metropolitana	7,007,620	48.97	14,307	6.7	13.7
	VI. O'Higgins	900,163	4.50	10,243	5.5	11.7
Centro Sur	VII. Maule	1,023,686	3.69	7,382	5.8	18.8
	VIII. Biobío	2,061,544	7.95	7,898	8.0	26
	IX. Araucanía	986,397	2.24	4,654	7.4	28.2
	XIV. Los Ríos	381,720	1.22	6,563	5.3	20.5
Los Lagos (Region X)		856,971	2.47	5,910	4.1	18.1
Aysén (Region XI)		106,885	0.48	9,106	5.5	11.4
Magallanes (Region XII)		159,666	0.86	11,073	3.1	7.1
	Total population	**17,402,630**				

Table 15 shows the differences in wealth, unemployment and poverty that exist between the different regions of Chile. These considerations are important when developing marine energy policy as they define the market for energy and the availability and cost of hiring labour, as well as the development priorities of regional governments. *See also Recommendation 8-J and Recommendation 8-K, page 131.*

Table 16 presents some of the information on marine energy resources, infrastructure and energy markets that was used in the following regional analysis.

[19] Data from INE for 2012

[20] Data for 2012 from the Central Bank of Chile, Calculation based on subtotal regionalised national GDP.

[21] Calculations based on data from the Central Bank of Chile. Data for 2012 expressed in 2012 USD PPP. (CLP486,75/USD)

[22] Data from INE for 2012

[23] Data from UNDP 2011 http://www.pnud.cl/areas/ReduccionPobreza/datos-pobreza-en-Chile.asp

Table 16: Regional comparison of marine energy resources, infrastructure and energy markets

Factor	*Units*	Norte Grande	Norte Chico	Centro	Centro Sur	Los Lagos	Aysén	Magallanes	Pacific Islands
Marine energy resources									
Pacific coastline	*km*	1,242	1,229	486	1,195	831	1,213	2,619	73
Seabed shelf <100m deep	*km^2*	5,000	3,300	2,175	18,500	8,600	21,400	78,250	150
Wave climate[24]	*kW/m*	20-25	25-31	36-41	46-61	71-87	87-111	111-120	45-60
Wave power resource	*MW*	20,000	21,300	10,700	32,000	25,700	45,200	88,600	1,900
Key tidal sites	*Number*	0	0	0	1	7	3	14	1
Tidal power resource[25]	*MW*	0	0	0	14	1,067	220	3,560	12
Infrastructure									
Thermal power plants	*Number*	14	11	20	24	6	5	4	0
Hydroelectric	*Number*	6	4	29	42	11	4	0	0
Wind plants	*Number*	6	13	4	9	3	1	1	0
Solar plants	*Number*	30	2	0	0	0	0	0	0
Coastal substations	*Number*	10	8	9	9	7	0	0	2
Main ports[26]	*Number*	3	2	2	5	1	1	2	2
Tug vessels	*>50 G.T.*	19	2	17	16	9	1	9	0
Universities[27]	*Number*	20	13	59	34	6	3	3	0
Energy markets									
Population[28]	*Number*	1,098,453	1,023,760	9,696,956	4,453,347	856,971	106,885	159,666	6592
Grid network	*System*	SING	SIC				Aysén	Magallanes	None
Registered fishing coves	*Number*	30	53	40	119	196	17	10	7
Aquaculture sites	*Number*	23	119	1	47	2,015	490	42	0
Mining sites[29]	*Number*	668	3,686	1,419	241	0	14	25	0
Mains water supply	*% house-holds*	97%	96.3	97.5	82.0	82.2	92.6	98.3	n/a
Desalination plants	*Number*	6	3	0	0	0	0	0	0

[24] Provided by Baird & Associates S.A., who hold detailed wave resource data for the entire Chilean coast

[25] Aquatera estimations based on mean depth, section width and speed – more detailed assessments are required

[26] http://web.directemar.cl/estadisticas/maritimo/default.htm (Also source of tug vessel data)

[27] http://servicios.universia.cl/contenidos/mapas/

[28] http://www.ine.cl/canales/menu/publicaciones/compendio_estadistico/pdf/2012/estadisticas_demograficas_2012.pdf

[29] http://www.sernageomin.cl/sminera-atlas.php

It is clear from that the challenges and opportunities facing the development of wave and tidal energy differ greatly from region to region. The following sections of this report consider the development potential of each of the marine energy regions (Figure 45), in order to propose development priorities for each. These proposed priorities are summarised in Table 17 at the end of this chapter. Analysis is supported by maps of the different regions (see key, Figure 48). Data for these maps was sourced in 2013 from the following sources:

Map references

Wave resource information based on a deep water wave model was provided by Baird & Associates S.A., who hold wave resource data for the entire Chilean coast at a higher resolution than is shown on these maps and have also made the first approximations of wave energy in shallower waters in Chile (Acuña S & Monárdez S, 2007) (Monárdez, et al., 2008) (Baird & Associates, 2012).

Regional and provincial data - obtained from the Military Geographic Institute (IGM).

Bathymetry data - obtained from GMRT multi-beam data, merged with lower-resolution compilations including the General Bathymetric Chart of the Oceans (GEBCO 08), the International Bathymetric Chart of the Arctic Ocean (IBCAO), and the SCAR Sub-glacial Topographic Model of the Antarctic (BEDMAP).

Fishing coves and salmon farms data - obtained from the Ministry of Fisheries and Aquaculture.

Electricity grid and renewable energy projects - provided by the Chilean Ministry of Energy.

Protected areas - obtained from the Chilean Environmental Ministry.

Desalination plants - obtained from the Chilean Environmental Assessment Service.

Mining sites - obtained from the Chilean Ministry of Mines.

Installed generation capacity data for 2012 - obtained from www.centralenergía.cl

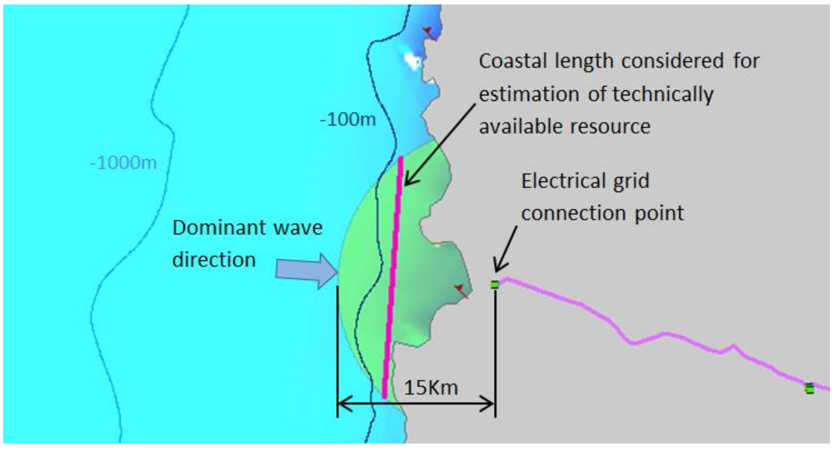


Figure 46: Methodology for approximation of technical wave resource

Pacific coastline lengths were obtained from Aquatera´s ArcGIS mapping system as shown in Figure 46.

Simple estimations of the technical wave resource for each region were made by considering coastal lengths inshore of the 100m depth contour and perpendicular to the dominant wave direction which are within 15km of an electrical grid connection (Figure 46). This is a very simple approximation which does not include the resource available at off-grid locations, nor does it consider how many rows of devices could be installed or what their performance might be. The technical tidal resource is assumed simply to be 10% of the total resource. Resource analysis was not in the scope of this study but more work is required in this area, see Recommendation 5-B (page 41) and Recommendation 8-J (page 131) in particular.

Seabed shelf area is a relevant parameter when considering the space available for marine energy projects and was obtained through ArcGIS considering the area between the Pacific coastline and the 100m depth contour as shown in Figure 47.

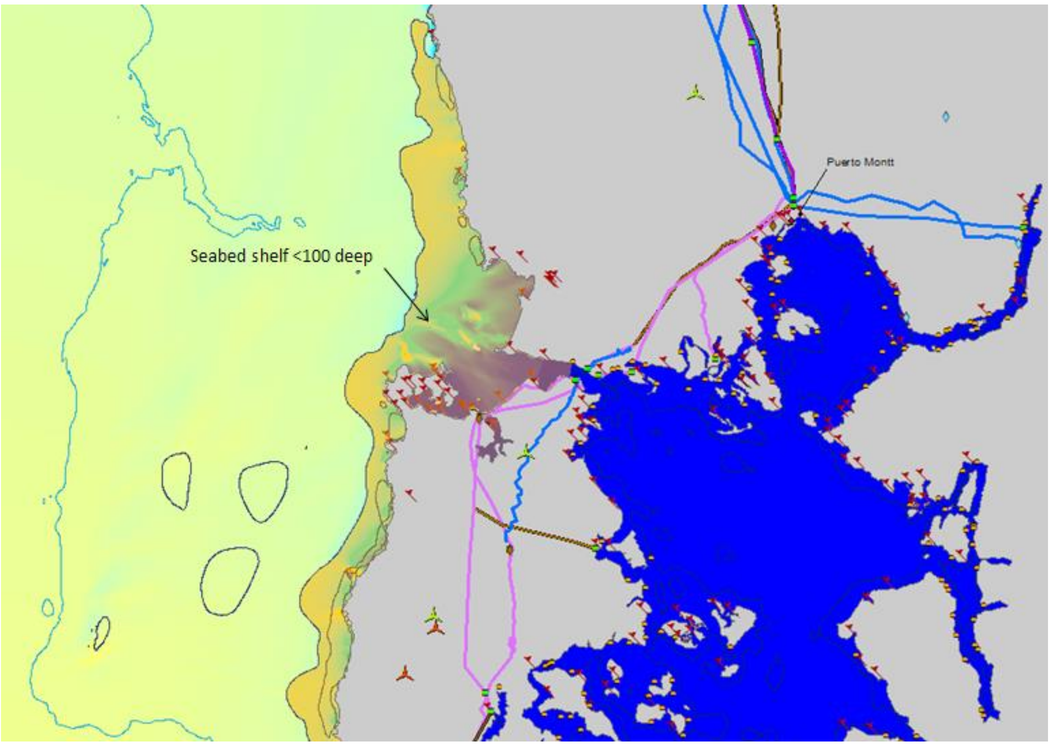
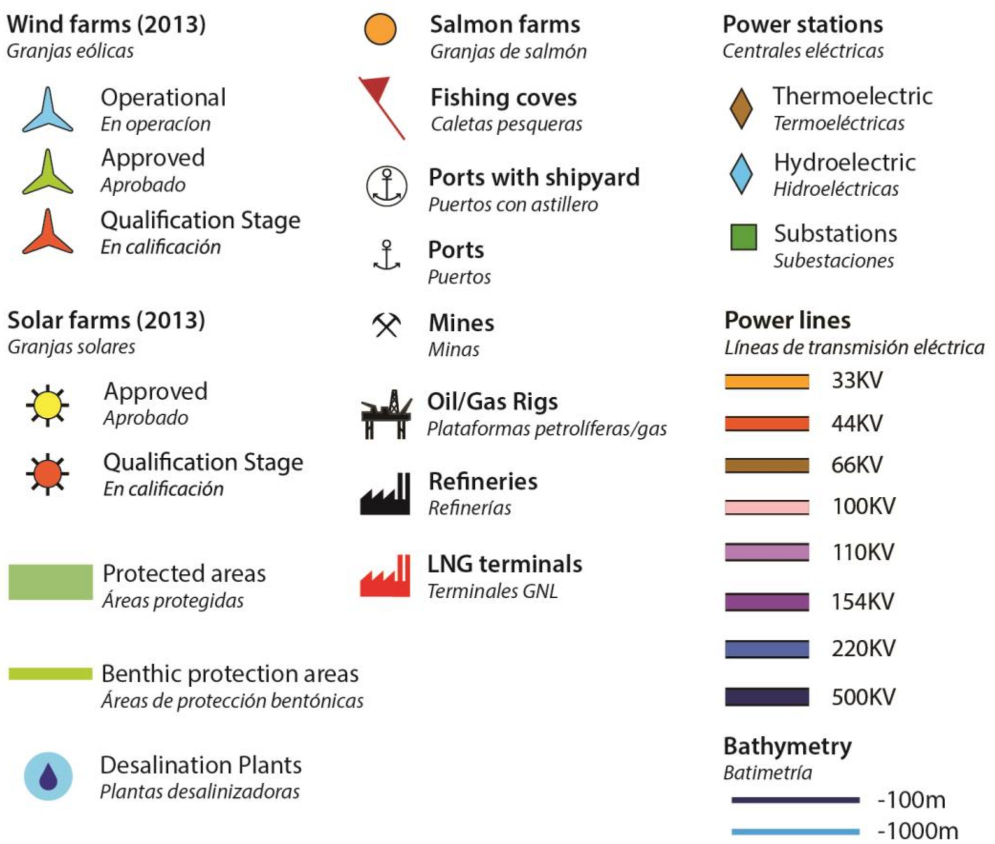
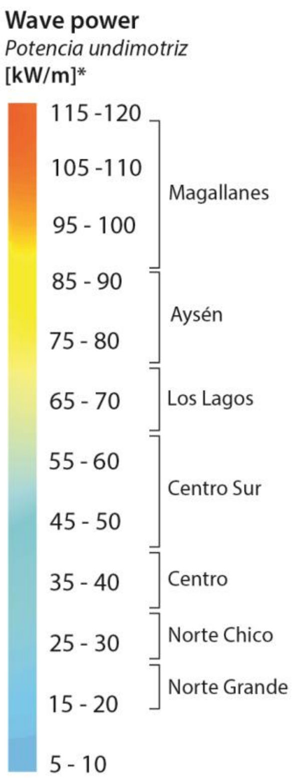


Figure 47: Methodology for estimation of seabed shelf area





Potential tidal energy sites
Sitios potenciales para energía mareomotriz

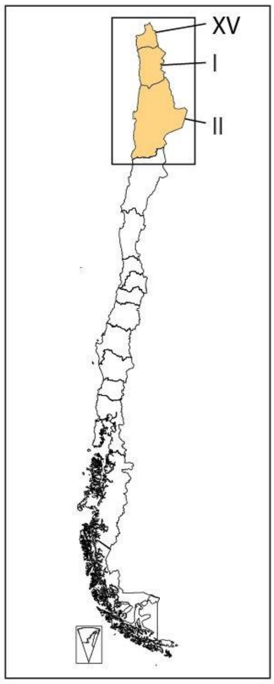
Location/*Localización*	Peak flow/*Flujo maximo* (m/s) Ebb tide *Marea vaciante*	Peak flow/*Flujo maximo* (m/s) Flood tide *Marea creciente*	Estimated mean kinetic power (MW) *Potencia cinética media estimada*
1. Robinson Crusoe	1.54	2.06	11.9
2. Isla Santa María	1.28	1.54	14.0
3. Canal de Chacao	4.63	2.57	800
4. Canal Calbuco	1.29	2.06	7.9
5. Estero Reloncaví	0.77	2.31	64.8
6. Canal Dalcahue	2.57	2.06	10.1
7. Bahía Quellón	0.51	2.06	2.7
8. Canal Chaiguao	0.51	2.06	5.0
9. Golfo Corcovado	0.51	2.06	31.1
10. Canal Carbunco	2.06	0.51	1.9
11. Canal Jacaf	0.51	2.57	89.2
12. Estero Elefantes	1.80	3.08	73.5
13. Angostura Inglesa	3.08	1.54	7.8
14. Angostura Kirke	4.63	6.17	33.2
15. Mal Paso	7.20	5.65	44.1
16. Canal Fitz Roy	2.16	1.54	6.3
17. Puerto Curtze	1.64	1.03	3.5
18. Isla Magdalena	1.03	2.06	14.7
19. Bahía Gente Grande	1.03	1.54	19.2
20. Segunda Angostura	2.06	2.57	734.7
21. Puerto Sara	2.06	2.57	514.5
22. Banco Tritón	1.03	2.06	7.1
23. Primera Angostura	2.57	4.11	1,727.2
24. Cabo Posesión	1.03	2.57	274.9
25. Punta Dungeness	1.03	2.06	31.1
26. Canal Beagle	1.03	1.54	42.8

*5kW/m is considered the minimum wave energy level feasible for generation

Figure 48: Map key

8.2 Norte Grande

8.2.1 Regional overview



XV. Arica y Parinacota
I. Tarapacá
II. Antofagasta

Norte Grande is the extreme north of Chile and consists of the administrative regions of Arica-Parinacota, Tarapacá and Antofagasta. This area is characterised by one of the driest deserts in the world - the Atacama - and water supply is an important challenge. The population is concentrated in coastal cities and a few productive valleys, beyond which there are large sparsely populated areas, with low rates of basic service provision in many isolated communities.

The main industrial activity is mining, which has fed strong growth in urban populations in recent years, pushing up demand for basic services and the cost of living. GDP per capita in the mining capital Antofagasta is more than triple the national average. Mining has also deepened the problems of water availability in the area, so desalination plants are becoming increasingly common. Other economic activities in the region include fishing, tourism, trade and services. Norte Grande depends predominantly on gas (47%) and coal (45%) for electrical power generation. As shown on the map below however, there are a number of solar projects which have been approved for construction.

Wave energy levels are lower than in the rest of Chile but still high enough for power generation, ranging from 20 to 25 kW/m. The cost of installing and maintaining equipment is also likely to be lower in these more benign conditions. Norte Grande has an exposed coastline of approximately 1242km with few significant bays or coastal inlets. Offshore, the seabed drops away steeply, with a relatively narrow strip of seabed where water depths are less than 100m and therefore suitable for moored wave power devices. The total shelf area nonetheless amounts to around 5000km^2. There are no significant tidal resources.

8.2.2 Regulatory framework

The regions of Arica-Parinacota and Tarapacá are designated free trade zones and benefit from tax exemptions, in common with the regions of Magallanes, Aysén and parts of Los Lagos - see Figure 40 on page 79.

The Arica Plan is a tax reduction of up to 40% for investment in productive activities and is available in the Arica-Parinacota region. This instrument is aimed at attracting foreign industries to use the region as a centre of industrial development for the South American market. As well as the tax break of 40%, customs formalities and the payment of export and import fees are simplified.

The Antofagasta region is not part of the free trade zone, but there are plans to allow part of the tax revenue levied from mining to be invested in the region (at present over 85% of the tax collected in Norte Grande is invested in the central/southern regions).

All of these incentives have the potential to support the development of marine energy projects in the region and are already having positive effects on the profitability of solar and wind projects.

8.2.3 Research, Development and Innovation capability

The University of Tarapacá (in Arica and Iquique) is currently actively involved in aquaculture and fisheries research and has begun working on renewable energy projects. The Centre for Energy Studies of Arturo Prat University in Iquique, whilst focused on solar energy, intends to incorporate marine energy within the scope of future activities. The University of Antofagasta has a Centre for Energy research which plans to study Norte Grande´s wave energy potential.

8.2.4 Infrastructure and supply chain

The electrical grid in Norte Grande (*Sistema Interconectado Norte Grande, SING*) is not connected to the rest of Chile. There are many thermal power plants located on the coast which supply mining projects in the interior, so there are many direct connections between large generators on the coast and customers inland, whilst connections between different communities along the coast are less robust. The number of electrical substations near the coast may however help to facilitate the connection of marine energy projects.

Desalination and water pumping stations with their associated pipelines are also common and may transport desalinated or raw seawater over 100 kilometres inland to heights of more than 2,000m.

Norte Grande's three regional capitals are Arica, Iquique and Antofagasta and all possess general service ports. The high-capacity terminals in Arica and Iquique can receive post-panamax freighters while Tocopilla port is also of a suitable size to support marine energy projects. Iquique has sufficient shipyard capacity to build passenger and cargo vessels and could possibly manufacture marine energy devices.

8.2.5 Energy markets

Figure 49 compares actual installed generation capacity in the SING network (Central Energía, 2012) to estimated total and technical wave resources. It should be noted that there are no significant tidal resources in this region but that the total wave resource far exceeds current electricity demand.

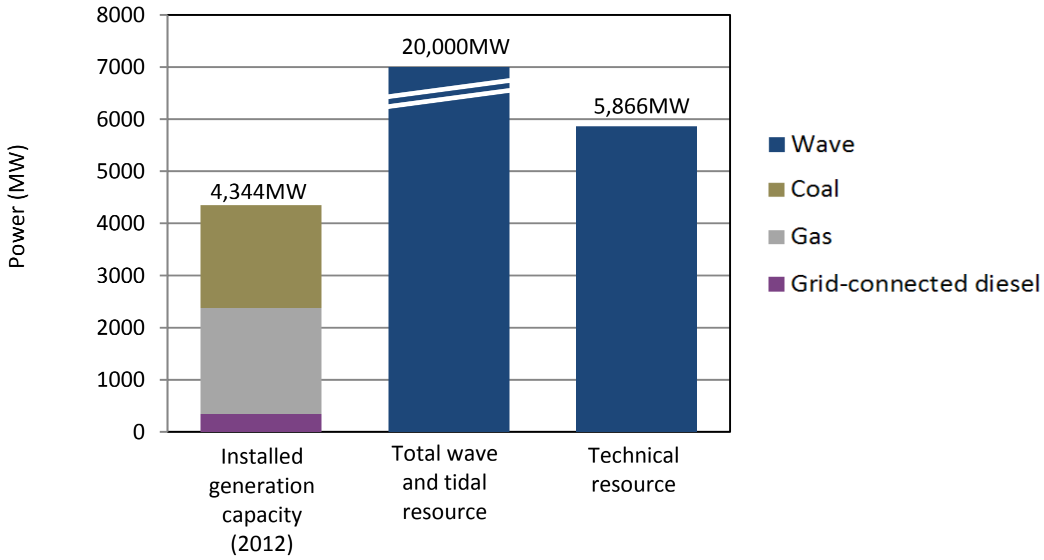


Figure 49: Installed generation capacity compared to marine energy resources (SING)

Also, as shown in the map of Norte Grande provided below, there are many coastal substations with robust grid connections. It is clear that the potential for wave power to supply the grid with electricity in Norte Grande is high.

Norte Grande has many fishing coves, aquaculture[30] sites and remote communities which are not grid-connected and depend largely upon diesel generation to fulfil their energy requirements[31]. A significant proportion of Norte Grande's population resides in areas which have no access to the SING electricity network. Diesel generation is expensive and transportation costs to remote areas increase the burden on these communities. Many of the isolated communities in Norte Grande are located on the coast with immediate access to consistent year-round wave energy. Such communities have an opportunity to replace or reduce diesel generation using wave energy devices, possible as part of an integrated renewable system which could include solar energy. Wave power projects can complement solar projects, as production can be maintained during hours of darkness.

Mining is the main activity in the region and uses a huge amount of fresh water. In some cases this is locally sourced fresh water, but increasingly raw or desalinated seawater is pumped inland. To preserve fresh water for agriculture and community use, the regional government of Aríca-Parinacota passed a restriction in 2012 which requires mining companies to meet their fresh water needs from desalination only.

Wave powered desalination plants could supply fresh or desalinated water to the mining industry upon the availability of fresh water supplies in the region of Chile. Plans are already in place in Western Australia to develop the world's first wave power, zero emission desalination plant using Carnegie Wave Energy´s CETO hydraulic wave power technology. The plant would not only desalinate seawater but also produces electricity that could be used to pump water over substantial distances.

There are also certain mining processes which can use untreated seawater (e.g. as a coolant or for leaching). Some mining operations use many tens of thousands of cubic metres of seawater per day (ref. Table 8 on page 49). The transportation of the seawater by pipeline is costly and energy intensive. Large investments are being made in desalination plants, pumping stations and asociated power plants to satisfy the demands of the mining industry, which looks set to continue to grow for some time. Some hydraulic wave power devices (such as CETO or Aquamarine Power´s Oyster) can be used directly for seawater pumping. Given the large and growing demand of the mining industry for energy as well as desalinated and untreated sea water, it is clear that the potential market for wave energy projects is substantial.

[30] These are generally for Talapia or Dorado rather than the Salmon farmed in the south of Chile.

[31] Aquatera Ltd, Marine Energy Infrastructure Map of Chile, 2013

8.2.6 Conclusions – Norte Grande

Although wave energy levels in Norte Grande are lower than elsewhere in Chile, the wave regime is very consistent and still energetic enough for power generation. It may also be more straightforward (and therefore less costly) to install and maintain equipment in these relatively benign areas.

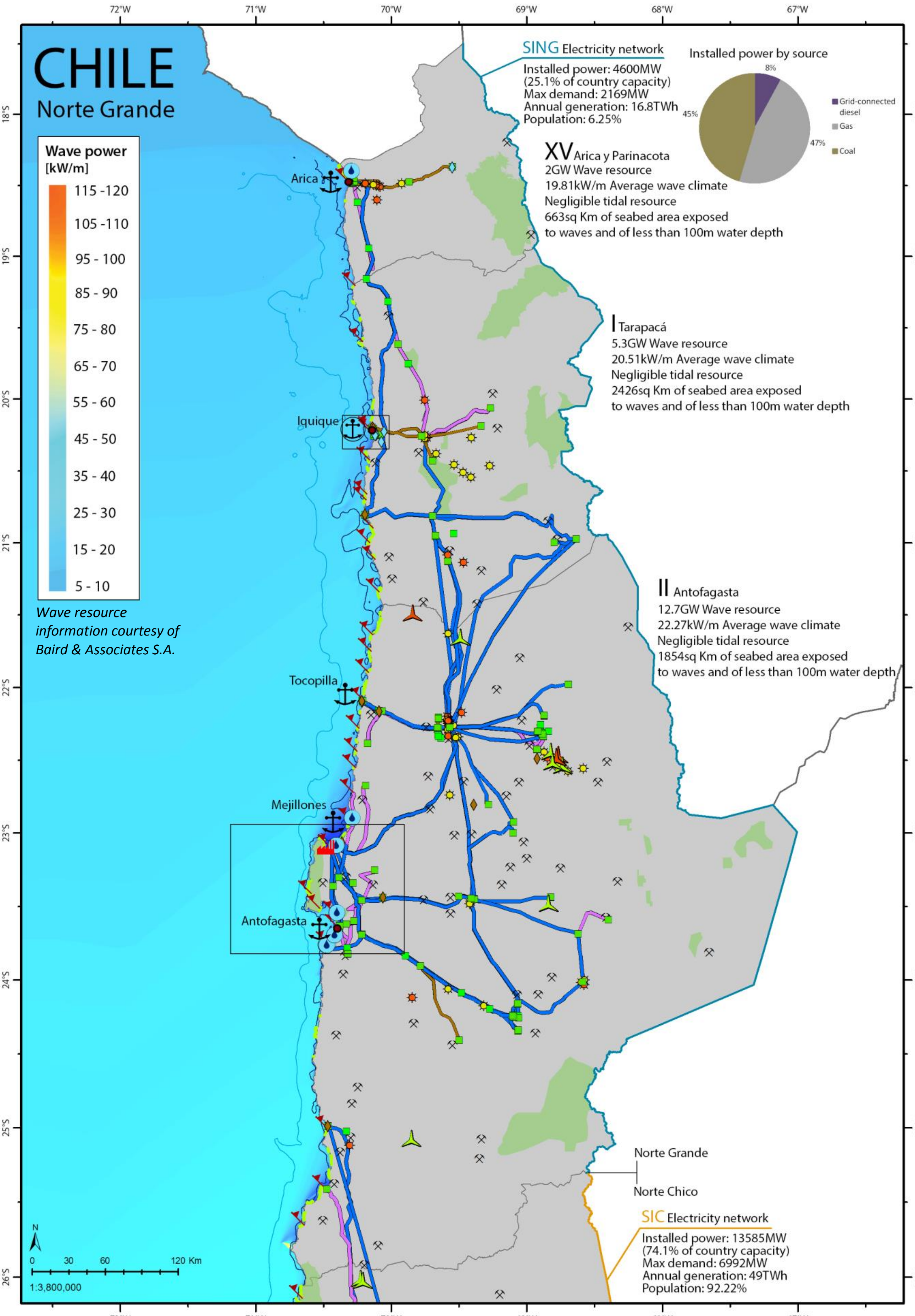
In the short term, water and energy demand could drive the development of smaller (possibly combined) wave energy and desalination plants for isolated communities. This is a market niche within marine energy where Chile could take a leading role and develop an extensive market at home and abroad. In the medium and long term, electricity demand is expected to rise due to continued growth in mining activity. High energy and water costs combined with tax benefits and a more benign operating environment could make wave energy projects viable earlier in Norte Grande than in more southern regions.

Recommendation 8-A: Marine energy development in Norte Grande

The **Regional Governments of Arica-Parinacota, Tarapacá and Antofagasta** may wish to consider how marine energy development could be encouraged in these regions, possibly through support for:

- A detailed assessment of the marine energy potential of these regions.
- The identification and designation of the most promising sites for development, in coordination with the coastline use commissions (**CRUBC**) and others.
- Feasibility studies for industrial scale wave-powered desalination or seawater pumping projects, in partnership with the mining industry and other sea users.
- Small scale wave power and desalination pilot projects in isolated areas.

Regional Governments / CRUBC **Short term**


CHILE
Norte Grande
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
SING Electricity network
Installed power: 4600MW
(25.1% of country capacity)
Max demand: 2169MW
Annual generation: 16.8TWh
Population: 6.25%
Installed power by source
8%
45%
47%
Grid-connected diesel
Gas
Coal
XV Arica y Parinacota
2GW Wave resource
19.81kW/m Average wave climate
Negligible tidal resource
663sq Km of seabed area exposed to waves and of less than 100m water depth
I Tarapacá
5.3GW Wave resource
20.51kW/m Average wave climate
Negligible tidal resource
2426sq Km of seabed area exposed to waves and of less than 100m water depth
II Antofagasta
12.7GW Wave resource
22.27kW/m Average wave climate
Negligible tidal resource
1854sq Km of seabed area exposed to waves and of less than 100m water depth
Arica
Iquique
Tocopilla
Mejillones
Antofagasta
Norte Grande
Norte Chico
SIC Electricity network
Installed power: 13585MW
(74.1% of country capacity)
Max demand: 6992MW
Annual generation: 49TWh
Population: 92.22%
72°W
71°W
70°W
69°W
68°W
67°W
18°S
19°S
20°S
21°S
22°S
23°S
24°S
25°S
26°S
N
0 30 60 120 Km
1:3,800,000

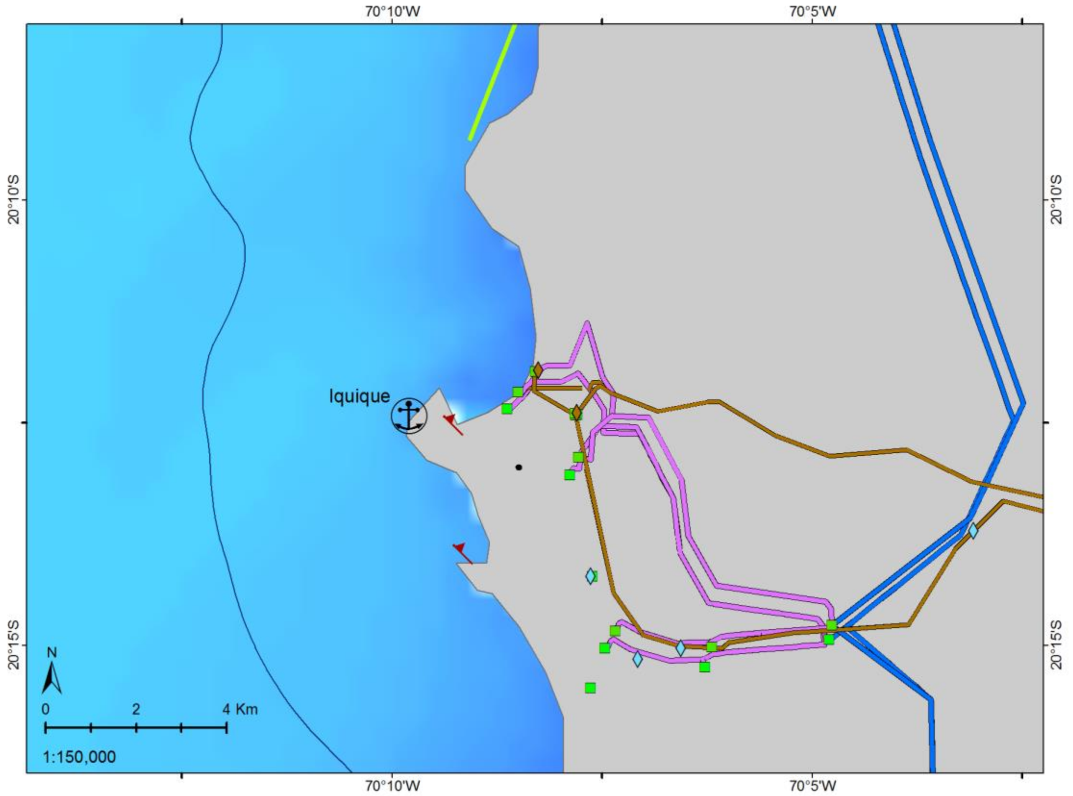


Figure 50: Norte Grande - Iquique inset

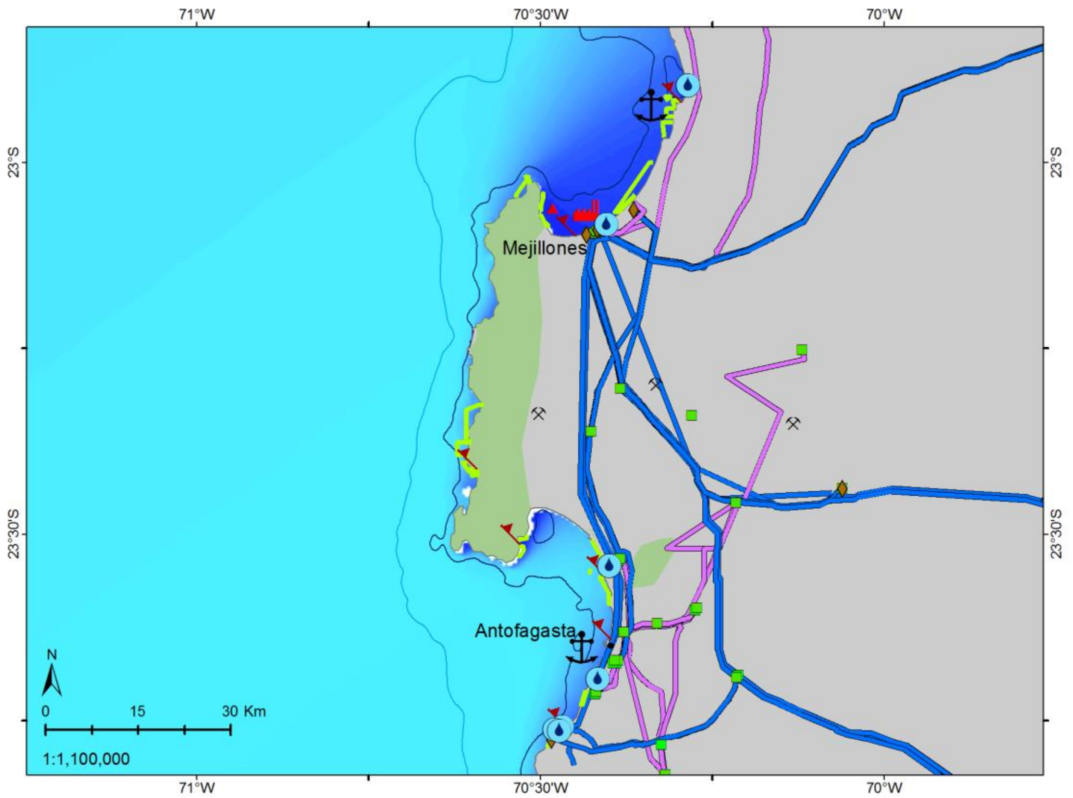
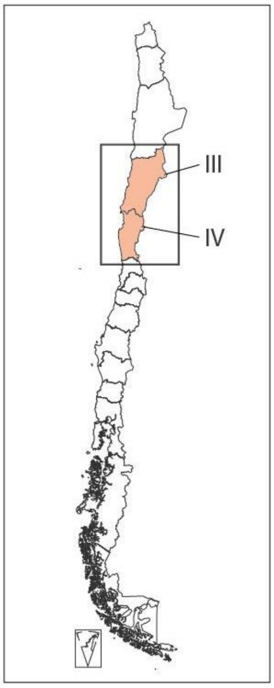


Figure 51: Norte Grande - Antofagasta inset

8.3 Norte Chico

8.3.1 Regional overview



III. Atacama
IV. Coquimbo

Norte Chico includes the administrative regions of Atacama and Coquimbo, and represents a transition zone between the northern desert and the mediterranean climate of the central zone. The climate is semi-arid, with productive valleys surrounded by large areas of arid lands. Population density is relatively low, but as in Norte Grande, mining activity is intensive. Agriculture and tourism are also important activities and aquaculture production (mainly of algae and shellfish) is growing. Around 84% of Norte Chico´s population of just over one million people live in urban areas and the remaining 16% in rural areas.

Wave energy levels range from 25 to 31kW/m off the coast of Norte Chico, slightly higher than in Norte Grande. There is approximately 1229km of exposed coastline but a relatively narrow coastal shelf, as the water depth increases rapidly offshore. In the south of Norte Chico there is more seabed space and electricity lines (part of the SIC network) near the coast. The total shallow shelf area is around 3300km^2.

8.3.2 Regulatory framework

Norte Chico benefits from the same centrally administrated funds as other regions of Chile, but there are few special regional development instruments or tax incentives.

8.3.3 Research, Development and Innovation (RD&I)

The University of Atacama in Copiapo and University Católica del Norte in Coquimbo are active in renewable energy development, currently focused on solar and wind energy. These institutions and others have expressed an interest in collaborating with other universities to study the wave energy potential in the areas.

8.3.4 Infrastructure and supply chain

Norte Chico is found at the northern end of Chile´s main central electricity network central grid (*Sistema Interconectado Central, SIC*). As shown in the map below, there are some substations and many planned windfarms along the southern coast of Norte Chico.

Coquimbo port has tugs and general service capacities, as to a lesser extent do the ports of Caldera and Puerto Las Losas. There are several industrial terminals for the export of mined materials, but these are generally specialised conveyor-belt piers with limited potential to support marine energy projects.

8.3.5 Energy markets

Figure 52 compares actual installed generation capacity in the SIC network (Central Energía, 2012) to the estimated total and technical wave and tidal energy resources for the marine energy regions of Norte Chico, Centro, Centro Sur and Los Lagos. It can be seen that the technical wave resource is estimated to be greater than current generation capacity. There are no significant tidal resources in Norte Chico.

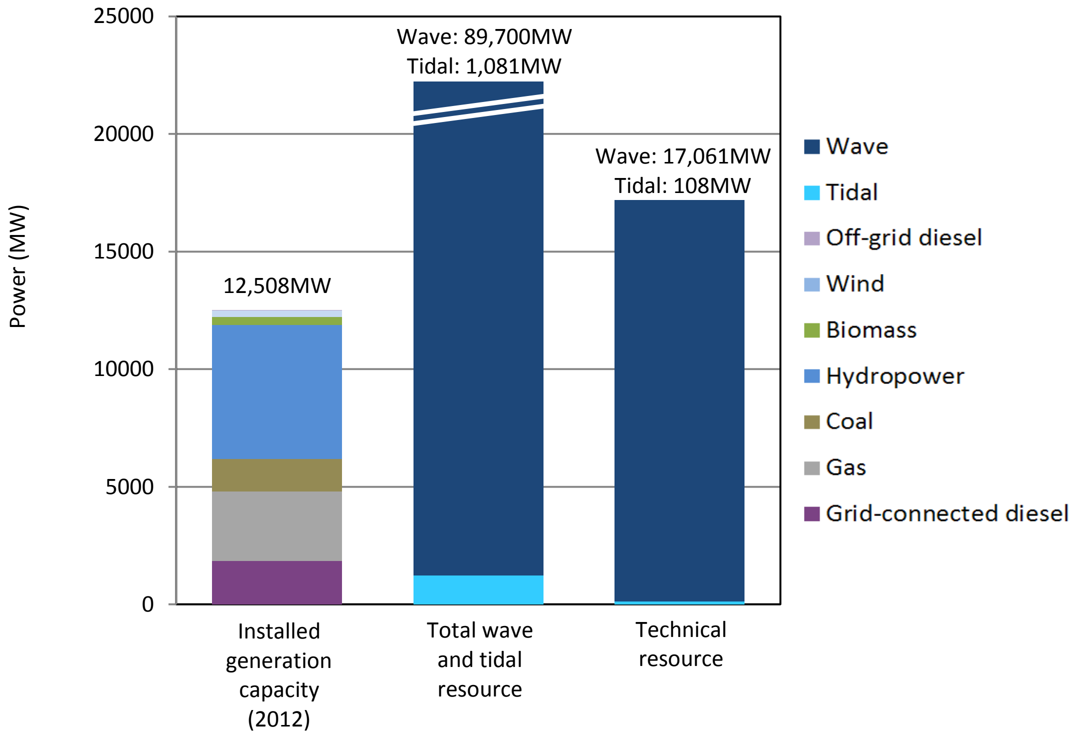


Figure 52: Installed generation capacity compared to marine energy resources (SIC)

Electricity demand is set to continue to rise in the SIC, and there are a number of coastal substations and grid connection points in Norte Chico which could be used for marine energy projects (note the large number of coastal wind farms on the map of Norte Chico below).

As described above for Norte Grande, in Norte Chico the mining industry is also the major consumer of electrical power in Norte Chico, and uses significant amounts of desalinated as well as untreated seawater.

Norte Chico has more than 50 registered fishing coves (see red flags on map below), and most of these sites lack grid electricity. These isolated fishing communities currently depend largely upon expensive diesel generation to meet their power requirements[32], and fresh water in many areas is brought in by road tanker.

One of the biggest solar plants in Latin America, the 100MW "*Amanecer Solar*" is to be constructed in Copiapó in the region of Atacama and as shown on the map below, many other solar farms have been consented. Wave power projects may eventually be able to play a role in balancing power requirement alongside these projects, as power production can be maintained during hours of darkness.

[32] http://web.directemar.cl/estadisticas/maritimo/2012/cuadros/122.pdf

8.3.6 Conclusions – Norte Chico

In addition to a strong market for grid electricity there is very large potential for wave energy to supply desalinated and raw seawater to the mining industry in Norte Chico, as there is in Norte Grande.

The development of smaller (possibly combined) wave energy and desalination plants for isolated communities is a market niche which has received comparatively little attention to date and could be a way of supporting the economic development of isolated communities, possibly in hybrid projects with other types of renewables.

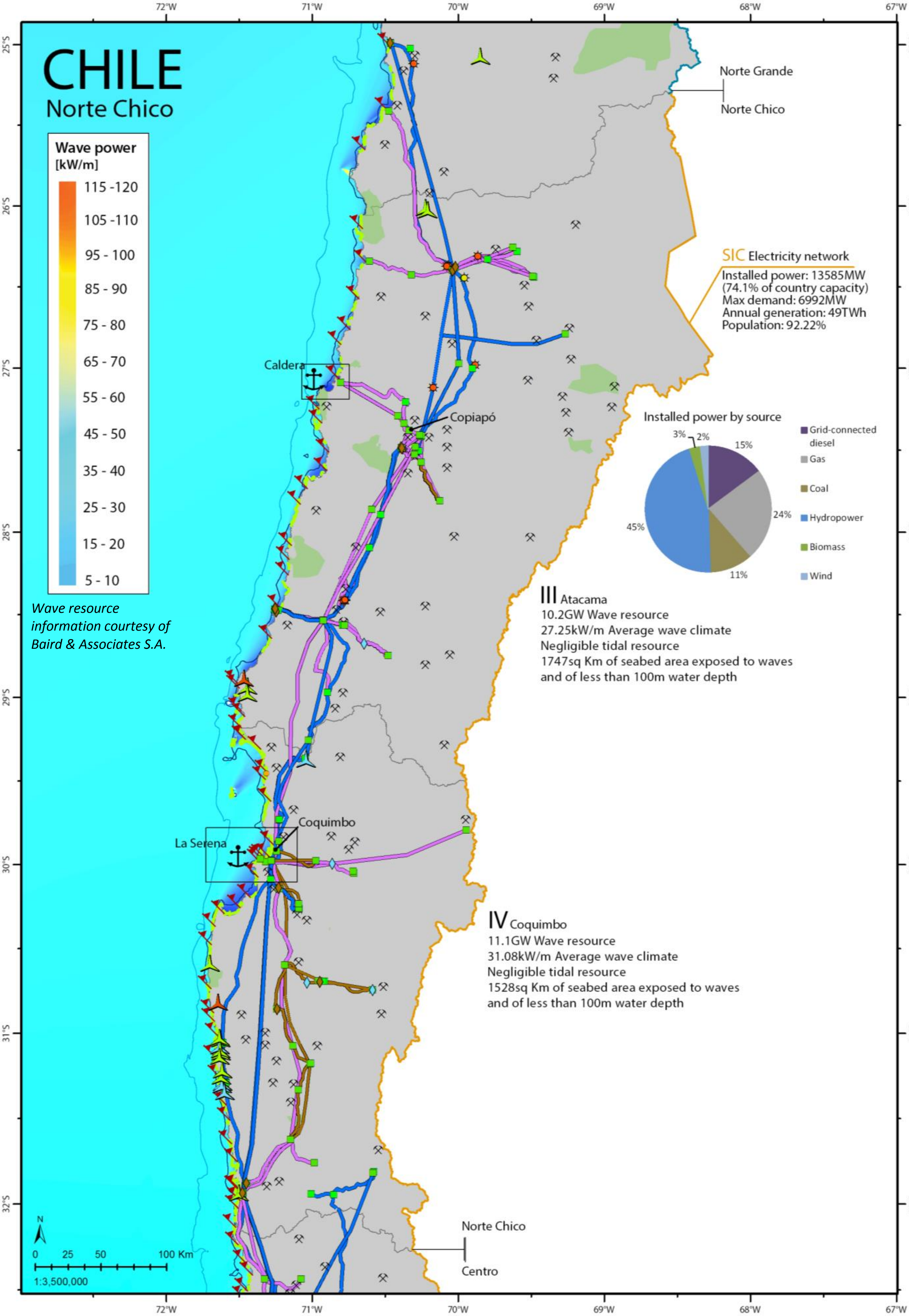
In the medium and long term, electricity demand is expected to rise due to continued growth in mining activity. The Coquimbo region, because of its proximity to the central area and relatively high wave energy levels, is likely to be attractive for the development of large-scale grid connected wave energy in the long term.

Recommendation 8-B: Marine energy development in Norte Chico

The **Regional Governments of Atacama and Coquimbo** may wish to consider how marine energy development could be encouraged in these regions, possibly through support for:

- Detailed assessment of the marine energy potential of the region in order to identify and reserve the most promising sites for development, in coordination with the coastline use commissions (**CRUBC**) and others.
- Feasibility studies for industrial scale wave-powered desalination or seawater pumping projects, in partnership with the mining industry and other sea users.
- Small scale wave power and desalination pilot projects in isolated areas.

Regional Governments / CRUBC **Short term**


CHILE
Norte Chico
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
Norte Grande
Norte Chico
SIC Electricity network
Installed power: 13585MW
(74.1% of country capacity)
Max demand: 6992MW
Annual generation: 49TWh
Population: 92.22%
Caldera
Copiapó
Installed power by source
3%
2%
15%
24%
45%
11%
Grid-connected diesel
Gas
Coal
Hydropower
Biomass
Wind
III Atacama
10.2GW Wave resource
27.25kW/m Average wave climate
Negligible tidal resource
1747sq Km of seabed area exposed to waves
and of less than 100m water depth
Coquimbo
La Serena
IV Coquimbo
11.1GW Wave resource
31.08kW/m Average wave climate
Negligible tidal resource
1528sq Km of seabed area exposed to waves
and of less than 100m water depth
Norte Chico
Centro
0 25 50 100 Km
1:3,500,000
72°W 71°W 70°W 69°W 68°W 67°W
25°S 26°S 27°S 28°S 29°S 30°S 31°S 32°S

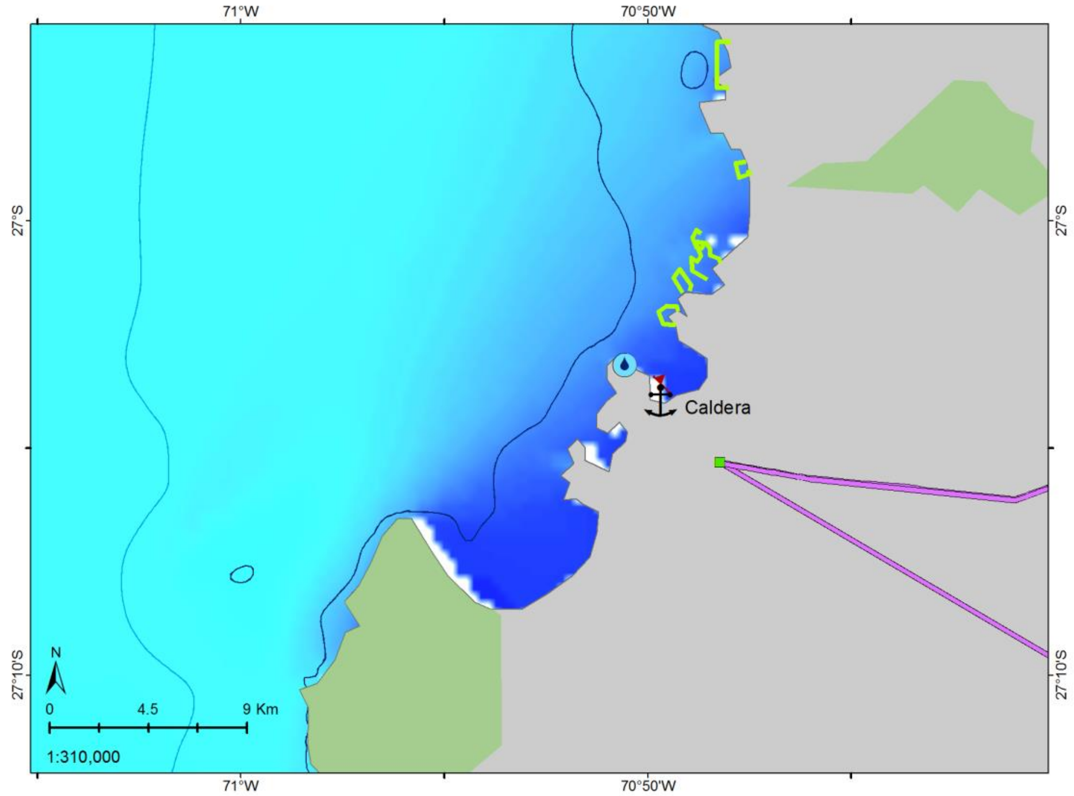


Figure 53: Norte Chico - Caldera inset

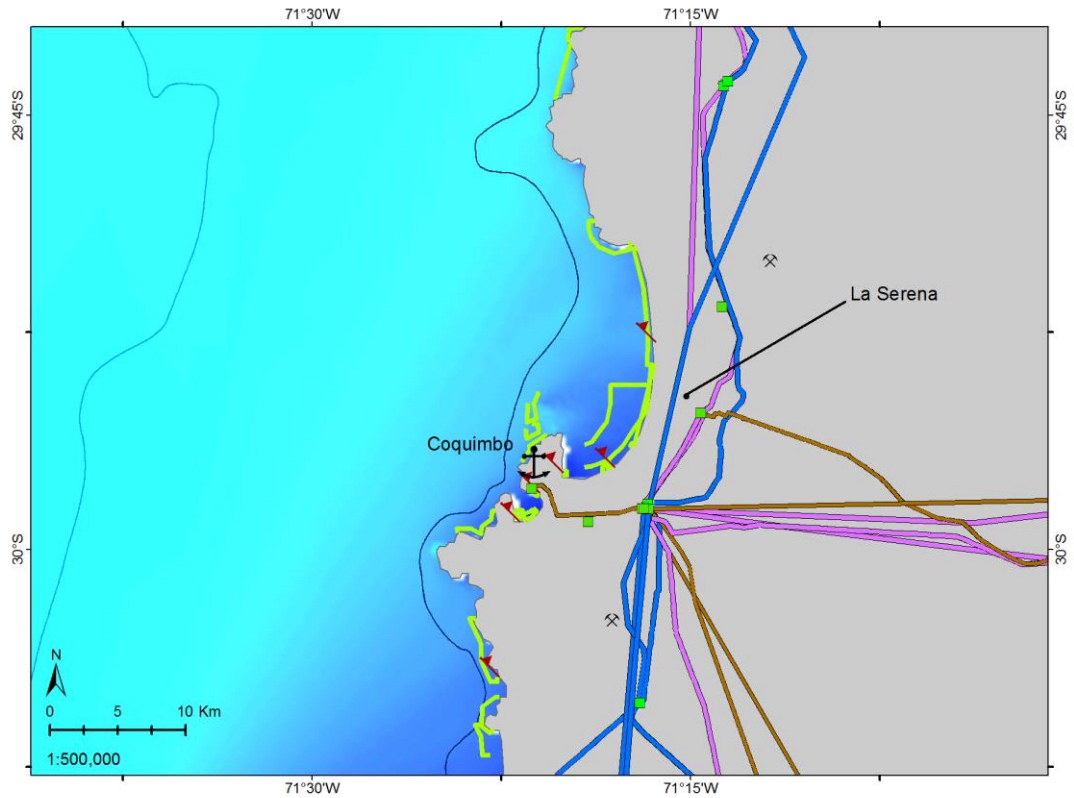
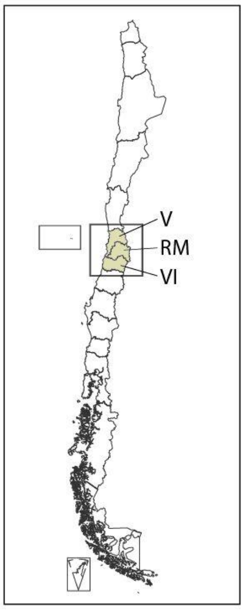


Figure 54: Norte Chico - Coquimbo inset

8.4 Centro

Centro & Islas del Pacífico



V. Valparaíso
RM. Región Metropolitana
VI. Libertador Gral. Bernardo O'Higgins

8.4.1 Regional overview

Centro comprises the central zone of Chile and includes the regions of Valparaiso, Región Metropolitana (RM) and O'Higgins. The region of Valparaíso also includes Chile´s Pacific islands. These are covered separately at the end of this section.

The climate in this area is Mediterranean, and population density is high. Just under ten million people live here - more than half of all Chileans. Only 7% of that total live in rural areas[33], and in O´Higgins there are a number of relatively isolated coastal settlements. Various trade and service industries are concentrated in the metropolitan region, with agriculture, agri-industry and tourism making up most of the rest of the economic activity.

This area accounts for much of the electricity consumption in the SIC network but is responsible for only a small part of generation, from some thermal power plants. Wave resource levels are moderately high, ranging from 36 to 41 kW/m. The "shadow" effect of the various headlands in shielding the coast further north from the south-westerly swells should however be noted (see map below). There are no significant tidal streams.

Centro has a wave-exposed coastline of approximately 468km for Valparaíso and O'Higgins regions (Región Metropolitana is the only region in Chile with no coastline). The coast has a narrow shallow shelf area of around 2175km^2 where water depths average less than 100m, as the seabed drops steeply offshore.

This region relies on a mixture of thermal and hydroelectric electricity generation, with 20 thermal and 29 hydroelectric plants plus four wind farms in Valparaíso and O'Higgins[34].

8.4.2 Regulatory framework

The central zone benefits from the same centrally administrated funds as other regions of Chile, but there are few special regional development instruments or tax incentives which would be applicable to marine energy projects. There are however a number of logistical and other advantages resulting from close proximity Chile´s regulatory and financial capital Santiago in Región Metropolitana.

8.4.3 Research, Development and Innovation (RD&I)

Many of Chile´s main universities and RD&I centres are found in Centro, including several which are active in marine energy related research (examples in brackets):

- Federico Santa María Technical University (electronics, electrical networks);
- Catholic University of Valparaiso (energy resources and oceanography);
- Valparaiso University (ocean engineering, installation of energy devices);
- University of Chile (renewable energy studies, electrical engineering);
- Catholic University of Chile (resource modelling, environmental assessment);

[33] http://www.ine.cl/canales/menu/publicaciones/compendio_estadistico/pdf/2012/estadisticas_demograficas_2012.pdf

[34] From GIS data provided by the Ministry of Energy of Chile

- Adolfo Ibañez University (energy innovation centre, marine energy presentations);
- National Hydraulic Institute (partner in wave and tidal resource assessment project);
- Other applied research centres such as DICTUC and CASIM have also been active in marine energy related projects.

8.4.4 Infrastructure and supply chain

There is good electrical grid capacity along the coast of Valparaiso region (see map below). The region of O´Higgins has limited grid near the coast.

Valparaiso and San Antonio are large and well-equipped ports. Tugs and other specialised vessels, shipbuilding, electronics and mechanical workshops, marine diving, and other engineering services are all available. The proximity to the Chilean capital has a number of logistical advantages.

8.4.5 Energy markets

The primary energy market in the region of Valparaiso is likely to be grid-connected electricity production, whereas in O´Higgins direct users may be a more important, at least until the grid is developed (see maps below). There are a number of coastal settlements and fishing coves in O´Higgins where wave power could be used directly.

Figure 52 on page 100 compares actual installed generation capacity in the SIC network (Central Energía, 2012) to the estimated total and technical wave and tidal energy resources for the marine energy regions of Norte Chico, Centro, Centro Sur and Los Lagos. The technical wave resource in the SIC is greater than the current electrical demand. There are no significant tidal resources in Centro.

8.4.6 Conclusions - Centro

The central zone of Chile is likely to play a key role in the development of the country´s marine energy supply chain device - structures and components could be manufactured here. Collaborative planning between the private and public sector is required to promote the development of local industry (see Infrastructure and Supply Chain, Chapter 6).

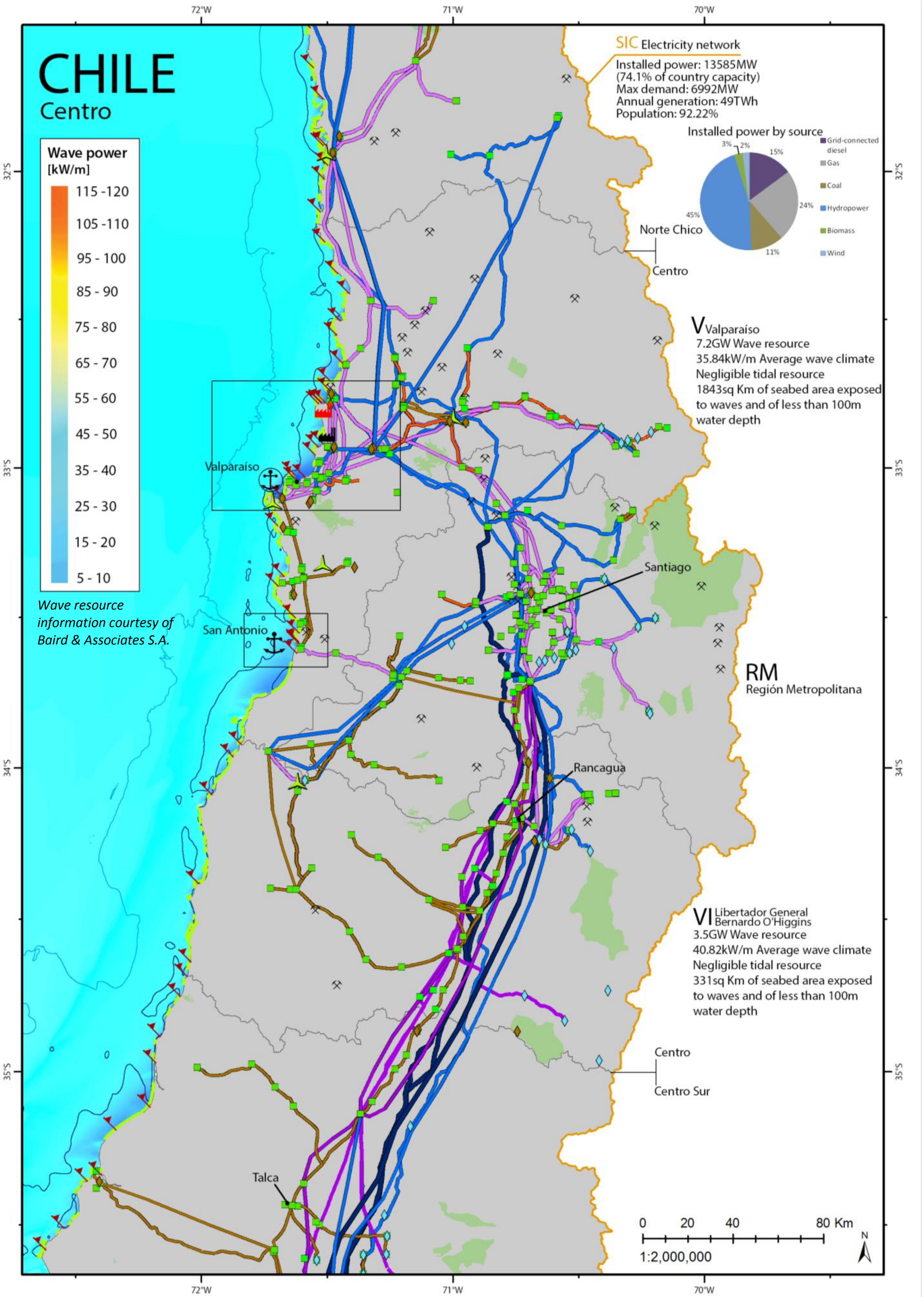
Given the high population density and intensity of marine and coastal activity in this zone, perhaps the most urgent challenge is to identify and reserve areas with potential for wave energy development (see marine planning, section 4.5).

Recommendation 8-C: Marine energy development in Centro

The **Regional Governments of Valparaiso and O'Higgins** may wish to consider commissioning a detailed assessment of the marine energy potential of the region in order to identify and reserve the most promising sites, in coordination with the coastline use commissions **(CRUBC)** and others.

Marine energy infrastructure and supply chain planning (see section 6.2.2) may be a logical priority for marine energy development support in this region, including for the **Metropolitan Region (RM)**.

Regional Governments of Valparaiso, RM and O'Higgins / CRUBC **Short term**


CHILE
Centro
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
SIC Electricity network
Installed power: 13585MW (74.1% of country capacity)
Max demand: 6992MW
Annual generation: 49TWh
Population: 92.22%
Installed power by source
Grid-connected diesel
Gas
Coal
Hydropower
Biomass
Wind
3%
2%
15%
24%
45%
11%
Norte Chico
Centro
V Valparaíso
7.2GW Wave resource
35.84kW/m Average wave climate
Negligible tidal resource
1843sq Km of seabed area exposed to waves and of less than 100m water depth
Valparaíso
San Antonio
Santiago
RM
Región Metropolitana
Rancagua
VI Libertador General Bernardo O'Higgins
3.5GW Wave resource
40.82kW/m Average wave climate
Negligible tidal resource
331sq Km of seabed area exposed to waves and of less than 100m water depth
Centro
Centro Sur
Talca
0 20 40 80 Km
1:2,000,000
N
72°W
71°W
70°W
32°S
33°S
34°S
35°S

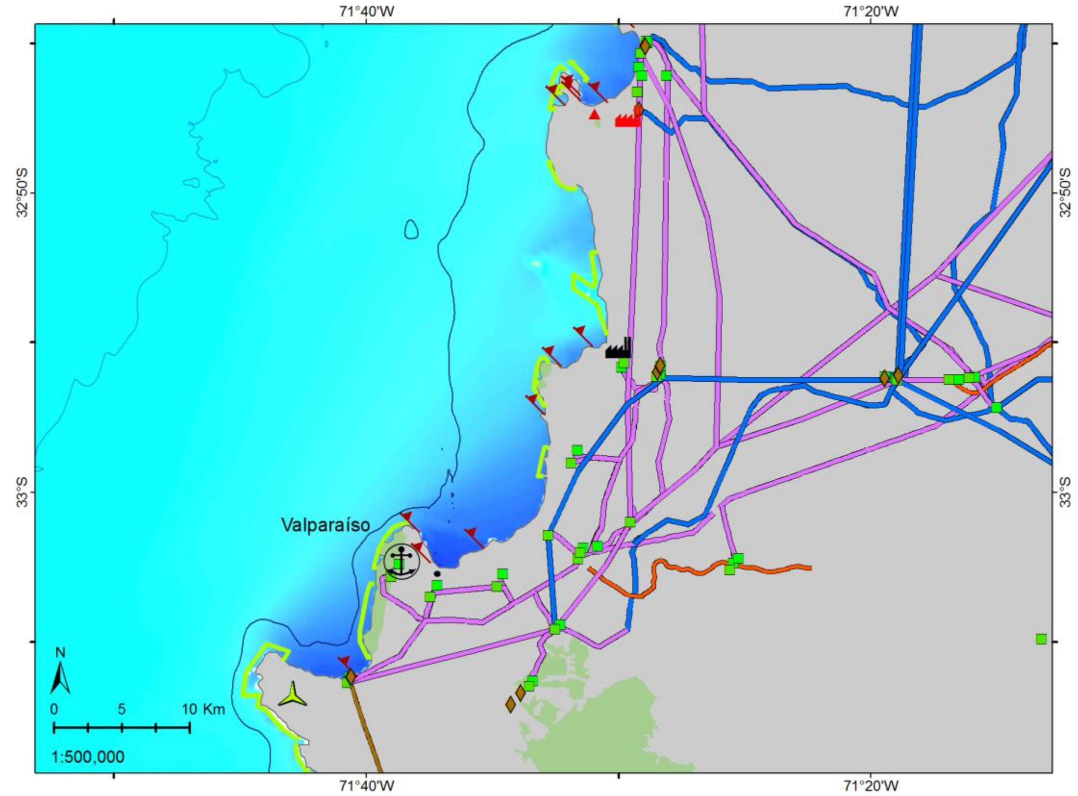


Figure 55: Centro - Valparaiso inset

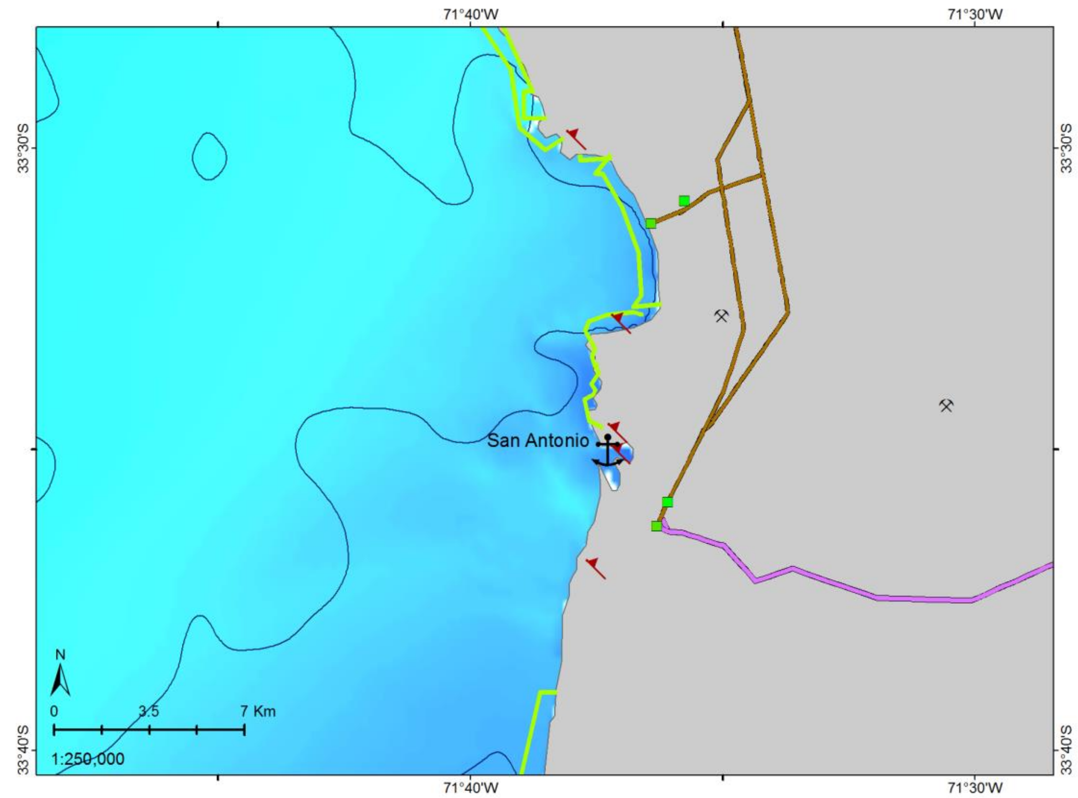


Figure 56: Centro - San Antonio inset

8.4.7 Pacific islands

The Pacific islands of Chile are part of the administrative region of Valparaíso. Easter Island and Robinson Crusoe are permanently inhabited with around 6,000 and 800 inhabitants respectively. There is also considerable increase in population during the tourist season[35]. There are a total of 7 registered fishing coves in the Pacific islands. Easter Island has a sizeable port with tugs which could support marine operations for wave and tidal projects.

Estimated wave energy levels are between 45-55kW/m for Easter Island and 50-60kW/m for Robinson Crusoe (see Figure 57). There is a potential tidal site between Santa Clara Island and Robinson Crusoe, with a tidal stream of approximately 2m/s and an estimated tidal resource potential of around 12MW.

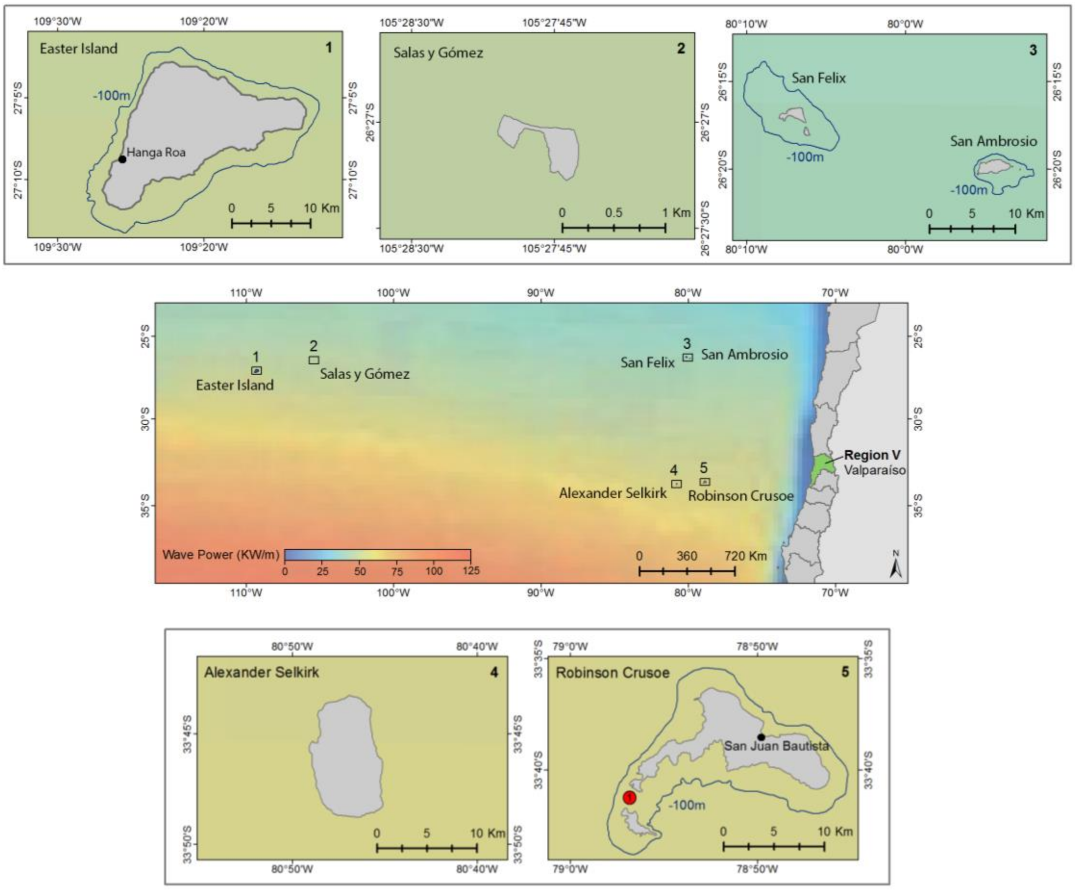


Figure 57: Pacific Islands of Chile[36]

All of the islands rely on diesel for electricity generation with a total installed power of 4.9MW in Easter Island and 1MW in Robinson Crusoe. Easter Island's electricity is supplied by SASIPA (*Agricola y Servicios Isla de Pascua*). On Robinson Crusoe, San Juan Bautista is supplied by three diesel generators with 1MW of total installed power[37].

[35] http://www.inevalparaiso.cl/archivos/files/pdf/Censo2012/Minuta%20Ejecutiva%20Censo2012.pdf

[36] Wave resource layer from OES in (E&A/UoE, 2012)

[37] http://antiguo.minenergia.cl/minwww/opencms/16_energias_limpias/construccion_planta_eolica/index.html

Due to the protected archaeological heritage of Easter Island, there may be restrictions on coastal construction works (e.g. for transformers or cable landing). In Robinson Crusoe, the Ministry of Energy has evaluated a wind energy project, as well as a proposal for developing a tidal power project.

The Chilean Pacific islands have an excellent wave potential while Robinson Crusoe has a known tidal resource (see map above). These islands have a high reliance on diesel for electricity generation, which must be shipped in at significant cost. These remote islands provide an exceptional opportunity for developing community scale marine energy projects and have access to specific subsidies which could support marine energy projects or related studies to facilitate the transition from diesel to renewable energy generation.

Recommendation 8-D: Marine energy development in the Pacific Islands

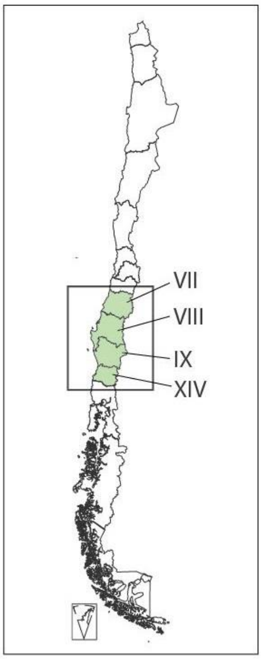
The **Regional Governments of Valparaiso** may wish to consider commissioning a study of the potential for marine energy to replace or reduce diesel consumption on Easter Island and the Juan Fernández archipelago, possibly as part of an integrated package of renewables with diesel back-up.

Regional Governments of Valparaiso / SASIPA **Short term**

8.5 Centro Sur

8.5.1 Regional overview

Centro Sur includes the administrative regions of Maule, Biobío, Araucanía and Los Ríos. This is a rainy temperate climate zone, a transition between the Mediterranean climate of central regions and temperate rainforests further south. After the central zone, this is Chile´s most populous area with a quarter of the population and Chile´s third largest city, Concepción. The population in the four regions of Centro Sur is around 4.5 million, 25.59% of Chile's overall population. 25% of the population live in rural areas, in contrast with Centro region where the figure is 7%[38].



VII. Maule
VIII. Biobío
IX. Araucanía
XIV. Los Ríos

There is a significant amount of industrial activity, particularly in Biobío where steel is produced. Other activities include agriculture, agro-industry, forestry and pulp production, fishing and tourism. Centro Sur has most of Chile´s hydroelectric generation capacity. Much of this power is transmitted for consumption in the central zone.

Wave energy levels are high and estimated between 46-61kW/m. Centro Sur has a Pacific coastline of approximately 1195km with a wide seabed shelf where water depths average less than 100m (18,500km^2).The shadow effect of the various islands and headlands in blocking wave energy is however important in this region (see areas around Concepción on map below).There are no important tidal streams although it is estimated that there may be around 14MW of tidal resource near the Isla Santa Maria and some other sites in Golfo de Arauco which could have sufficient currents for low-flow tidal generation devices.

[38] http://www.ine.cl/canales/menu/publicaciones/compendio_estadistico/pdf/2012/estadisticas_demograficas_2012.pdf

8.5.2 Regulatory framework

There are few specific development instruments and no special tax regimes in Centro Sur. Regional governments and local technical agencies in Biobío and Los Rios have however shown interest in studying the potential of wave energy in these regions.

8.5.3 Research, Development and Innovation (RD&I)

The oceanography and geophysical departments of the University of Concepción (UC) are active in marine energy research, including the development of high-frequency radars to measure wave and tidal resources. UC´s energy and environmental research groups also have some relevant marine energy experience - there is an ongoing project to model the spread of viruses from salmon farms in Aysén which may hold the best information on tidal currents in this region. The Catholic University of Santísima Concepción has developed a meteo-oceanographic buoy system. In Valdivia, Austral University specialises in naval engineering, and is active in marine energy with projects developing low-flow tidal turbines and integrated renewables systems for salmon farms. The University has a wave test tank as well as other research centres focused on energy and the environment, including the Blue Whale Centre.

8.5.4 Infrastructure and supply chain

Centro Sur depends on a combination of thermal and hydroelectric generation, with 24 of the former and 49 of the latter. In 2013 there were 9 wind energy farms in operation, located in Biobío and Araucanía regions. The electrical grid (SIC) is robust between Biobío region and metropolitan areas further north, but weaker nearer the coast. In Arauco, in the south of the Biobío region, wind projects have already been held up or cancelled due to a lack of grid capacity. Upgrades to the transmission system are planned which would alleviate the difficulty of access to the grid for projects, but for wave energy the lack of grid near the coast could be a barrier to future development in this region.

Centro Sur's four regional capitals are Talca, Concepción, Temuco and Valdivia. Talcahuano is one of the main ports in the country, with significant facilities, shipyards, workshops and specialised services available. ASMAR, the Chilean Navy´s shipbuilder, has its main facility in Talcahuano. In the Biobío region there is significant capacity in metalworking, associated to the local steel production. Valdivia is an excellent harbour which is also home to the ASENAV private shipyard, which builds modern, high capacity vessels and has links to Austral University. Towing services, workshops and other services of relevance to the marine energy sector are also available.

8.5.5 Energy markets

Figure 52 on page 100 compares actual installed generation capacity in the SIC network (Central Energía, 2012) to the estimated total and technical available wave and tidal energy resources for the marine energy regions of Norte Chico, Centro, Centro Sur and Los Lagos. The technical wave resource in the SIC is greater than the current electrical demand and there are many suitable sites to connect wave energy projects to the grid in Centro Sur (see maps below).

Centro Sur has the highest fishing activity in the country, with 31% of the total fish landings spread between the ports of Talcahuano, San Vicente and Coronel[39]. Centro Sur has the second highest number of fishing coves in the country, with a total of 119. Both the larger ports and smaller fishing centres have high energy demands, particularly for the freezing of fish and/or production of ice. As

[39] http://web.directemar.cl/estadisticas/maritimo/default.htm

for other regions, there is interesting potential for wave power to replace or reduce diesel consumption at these sites.

8.5.6 Conclusions – Centro Sur

Centro Sur has the potential to become a centre for device manufacturing and the deployment of large grid-connected wave farms. Between Lebu and Valdivia the seabed drops off less rapidly than in most other areas and there is more room for projects, but securing grid access may be easier closer to the population centres as would the identification and designation of priority zones for the development of wave power projects.

Recommendation 8-E: Marine energy development in Centro Sur

The **Regional Governments of Maule, Biobío, Araucanía and Los Ríos** may wish to consider identifying and reserving the most promising marine energy sites, in coordination with the coastline use commissions (**CRUBC**) and through consultation with other sea users.

Feasibility studies or pilot projects for off-grid wave energy projects could be particularly relevant in the regions of **Maule** and **Araucanía**, whilst infrastructure and supply chain development could be a logical priority area in the regions of **Biobío** and **Los Rios**.

Regional Governments / CRUBC **Short term**

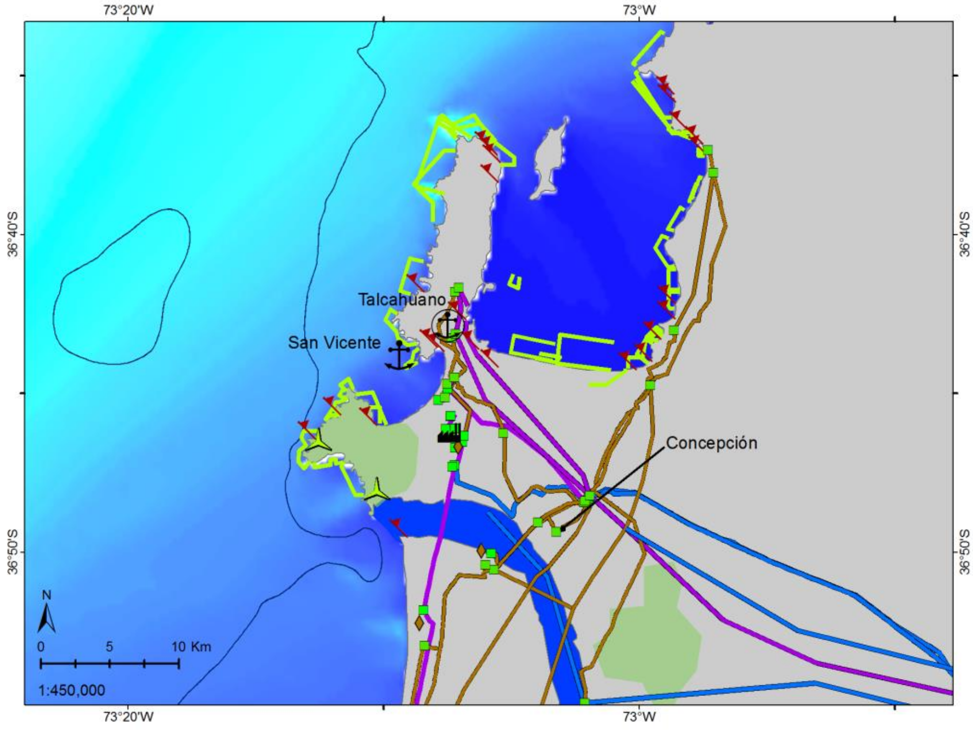
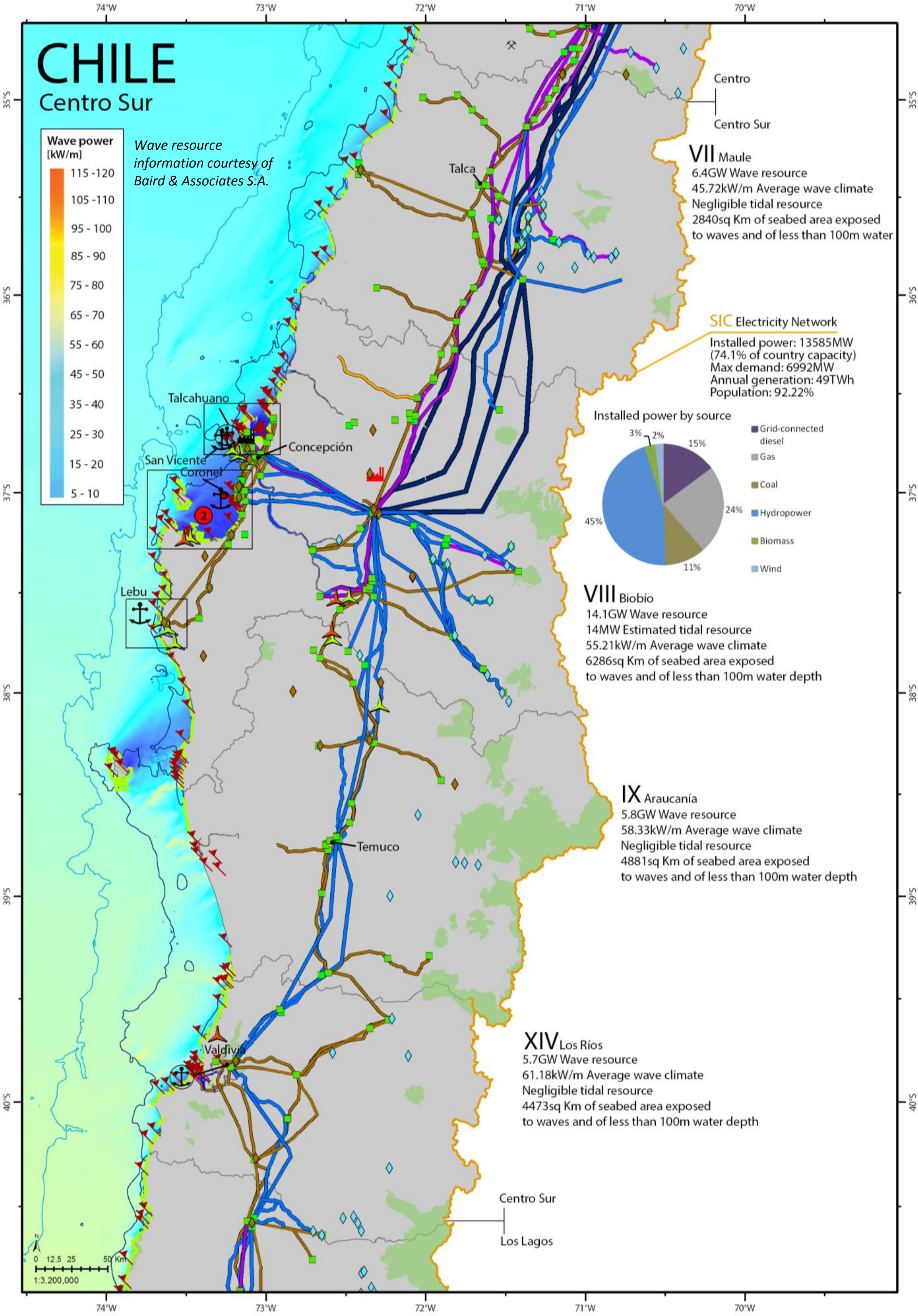


Figure 58: Centro Sur - Concepción/Talcahuano inset


CHILE
Centro Sur
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
Centro
Centro Sur
VII Maule
6.4GW Wave resource
45.72kW/m Average wave climate
Negligible tidal resource
2840sq Km of seabed area exposed to waves and of less than 100m water
Talca
SIC Electricity Network
Installed power: 13585MW
(74.1% of country capacity)
Max demand: 6992MW
Annual generation: 49TWh
Population: 92.22%
Installed power by source
Grid-connected diesel
Gas
Coal
Hydropower
Biomass
Wind
15%
24%
11%
45%
3%
2%
Talcahuano
Concepción
San Vicente
Coronel
Lebu
VIII Biobío
14.1GW Wave resource
14MW Estimated tidal resource
55.21kW/m Average wave climate
6286sq Km of seabed area exposed to waves and of less than 100m water depth
IX Araucanía
5.8GW Wave resource
58.33kW/m Average wave climate
Negligible tidal resource
4881sq Km of seabed area exposed to waves and of less than 100m water depth
Temuco
XIV Los Ríos
5.7GW Wave resource
61.18kW/m Average wave climate
Negligible tidal resource
4473sq Km of seabed area exposed to waves and of less than 100m water depth
Valdivia
Centro Sur
Los Lagos
74°W
73°W
72°W
71°W
70°W
35°S
36°S
37°S
38°S
39°S
40°S
0 12.5 25 50 Km
1:3,200,000

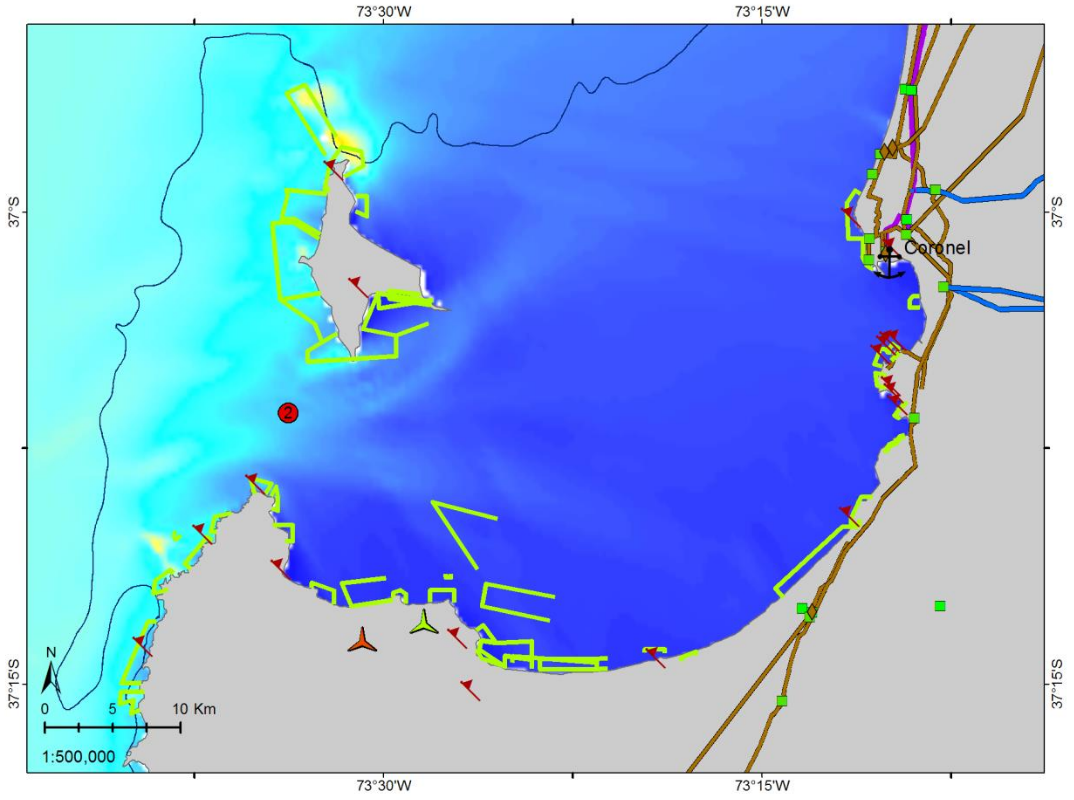


Figure 59: Centro Sur - Coronel inset

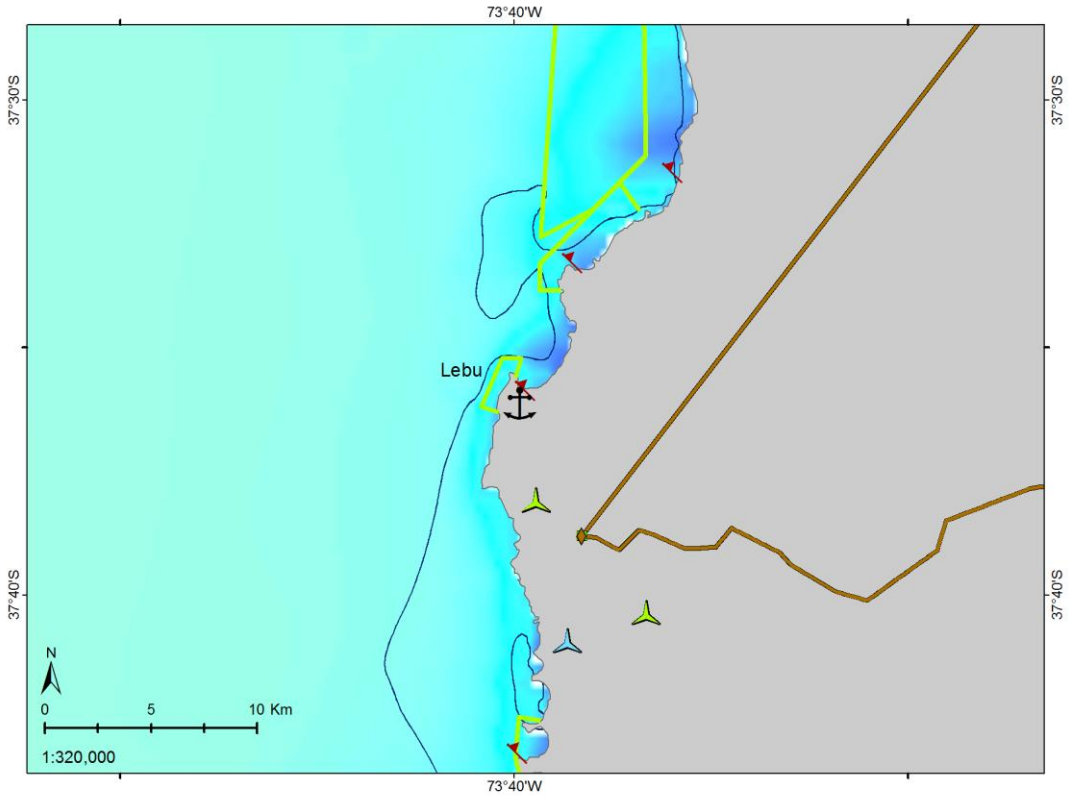
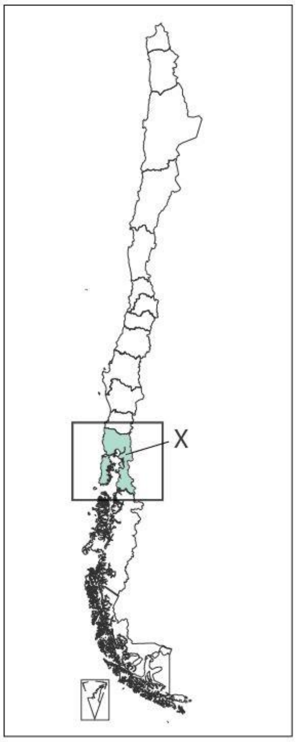


Figure 60**: Centro Sur - Lebu inset**

8.6 Los Lagos

8.6.1 Regional overview

The region of Los Lagos is located between latitude 40 and 44 degrees south, and marks the transition from mainland Chile to an area of fjords, islands and channels. With around 850,000 inhabitants, the main activities are aquaculture, fishing, forestry, livestock farming, craftsmanship and tourism. Around 30% of the population live in rural areas. The marine environment in Los Lagos is of international significance, not least due to the presence of blue whales.



X. Los Lagos

Los Lagos has a Pacific coastline of approximately 831km. The coast of archipelago of Chiloé which is exposed to the Pacific Ocean has a wide shallow shelf area of 8600km^2, where water depths average less than 100m. Wave energy levels are very high, between 71 and 87kW/m.

Los Lagos also has excellent tidal resources, particularly in the Chacao Channel but also in many smaller sites throughout the region. HydroChile is currently leading a FONDEF-supported project to evaluate the tidal resource and environmental conditions in the Chacao Channel, where the total resource is estimated at 800MW. The estimated total resource for Los Lagos is 1067MW.

8.6.2 Regulatory framework

The Regional Government of Los Lagos has a specific budget for studies and infrastructure projects which support remote and/or economically deprived areas. These funds could be used to support the development of marine energy projects in such areas.

8.6.3 Research, Development and Innovation (RD&I)

The Centre for Research and Development of Coastal Resources and Environment or I-Mar is part of the University of Los Lagos in Puerto Montt and carries out coastal environmental research, focusing on fishing and aquaculture. The Huinay Foundation has also completed a number of studies on the marine ecosystems of the channels and fjords in Los Lagos, and some private organisations carry out RD&I work for the salmon farming industry amongst others. Austral University has facilities in the region and conduct marine environmental research in the Chacao channel and further south.

8.6.4 Infrastructure and supply chain

The main electricity generation in Los Lagos is from the 11 hydroelectric and 6 thermal power plants located in this region. Additionally, there are 3 wind farms, one on the mainland and two on the island of Chiloé (see map below).

There is little grid capacity on Pacific-facing coast in Los Lagos, which is likely to be a barrier to the development of wave energy projects in the region. There are however substations adjacent to the second largest tidal resource in the country, the Chacao Channel and indeed the SIC grid spans this channel. A road bridge linking the Chiloé to the mainland is also planned. It is not clear whether it may be possible to incorporate tidal turbines into this construction.

Significant port and shipyard capacity in Puerto Montt, offering medium-sized shipyards, workshops, services for marine motors and marine electronics, steel and fiberglass construction, tugs, dive and survey teams amongst other services. Ancud, Castro, Quellón and Calbuco are smaller ports which could serve as bases for light maintenance or servicing of smaller marine energy devices. The existing capacities of the aquaculture industry could support marine energy projects from the site identification and permitting stages through to surveys, design, fabrication and maintenance of marine structures and equipment.

8.6.5 Energy markets

Figure 52 on page 100 compares actual installed generation capacity in the SIC network (Central Energía, 2012) to the estimated total and technical wave and tidal energy resources for the marine energy regions of Norte Chico, Centro, Centro Sur and Los Lagos. The technical wave resource in the SIC is estimated to be greater than current electrical demand. There are some suitable sites where wave energy projects could be connected to the grid in Los Lagos (see maps below).

There are also many remote communities and salmon farms scattered along the coast of Los Lagos region which are not connected to the SIC electricity network and are dependent on expensive diesel generation. Some of these areas, particularly along the coasts of Chiloé and Palena provinces, are exposed to waves or close to tidal streams which have the potential to be used for power generation. Projects which replace or reduce diesel generation in this way may be competitive sooner than those seeking to compete with lower electricity prices in the SIC. There are over 2,000 aquaculture concessions in Los Lagos region[40], the highest number in Chile. Los Lagos also has almost 200 fishing coves, the highest number of any region in Chile.

8.6.6 Conclusions – Los Lagos

Los Lagos has both wave and tidal energy resources in abundance and the region has the potential to become a natural laboratory for demonstration of both wave and tidal devices.

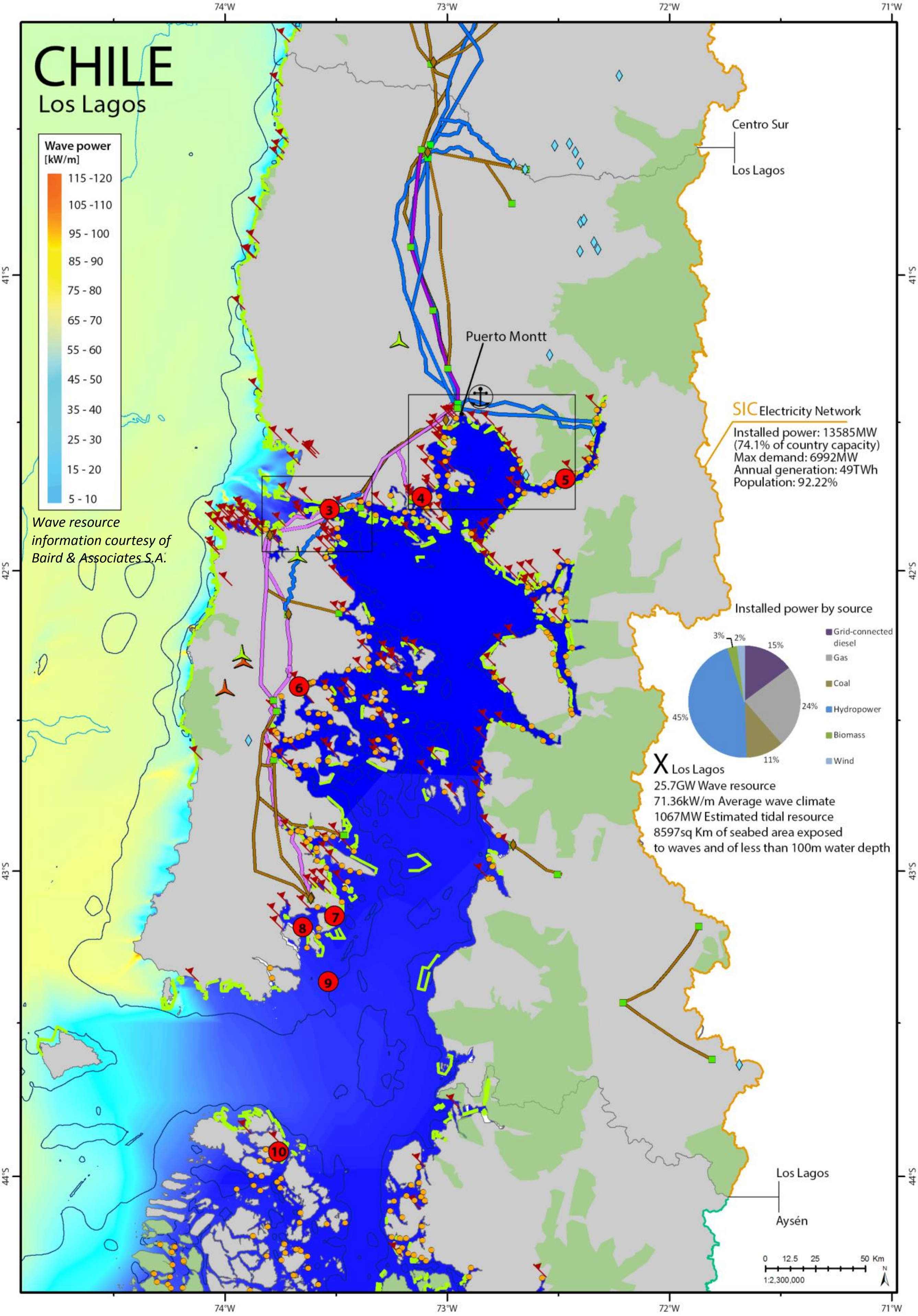
The Chacao Channel is the second most important tidal stream in Chile after the Magellan Strait, and projects here would be able to connect to Chile’s largest electricity network. Effort will be required to design a project which is environmentally and socially acceptable. The tidal resources in the numerous other channels need to be better understood.

Recommendation 8-F: Marine energy development in Los Lagos

The **Regional Government of Los Lagos** may wish to consider commissioning a study of the wave and tidal power potential in the region, to inform the development of a strategic plan for marine energy development. An appropriate tidal deployment in the Chacao Channel could showcase marine energy in Chile. The identification and designation of other promising marine energy sites in coordination with the regional coastline use commission (**CRUBC**) would also be beneficial.

Regional Government of Los Lagos / CRUBC — **Short term**

[40] http://web.directemar.cl/estadisticas/maritimo/default.htm


CHILE
Los Lagos
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
74°W
73°W
72°W
71°W
41°S
42°S
43°S
44°S
Centro Sur
Los Lagos
Puerto Montt
SIC Electricity Network
Installed power: 13585MW
(74.1% of country capacity)
Max demand: 6992MW
Annual generation: 49TWh
Population: 92.22%
Installed power by source
Grid-connected diesel
Gas
Coal
Hydropower
Biomass
Wind
3%
2%
15%
24%
45%
11%
X Los Lagos
25.7GW Wave resource
71.36kW/m Average wave climate
1067MW Estimated tidal resource
8597sq Km of seabed area exposed to waves and of less than 100m water depth
Los Lagos
Aysén
0 12.5 25 50 Km
1:2,300,000

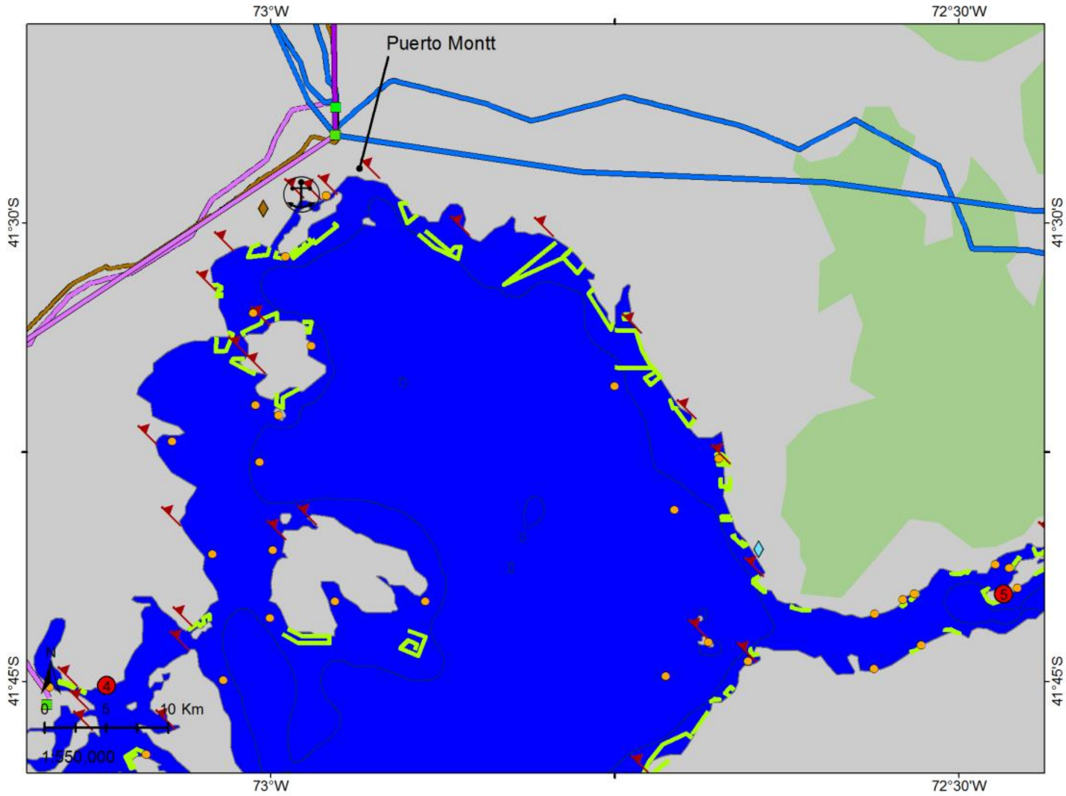


Figure 61: Los Lagos - Puerto Montt inset

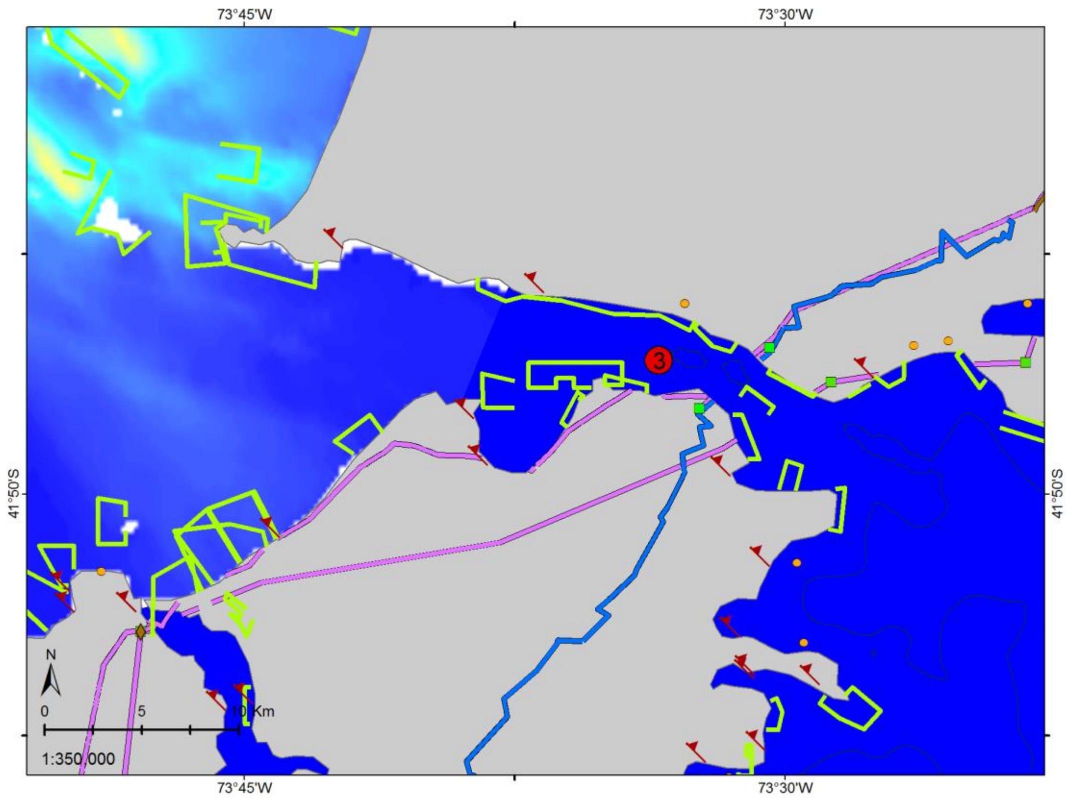
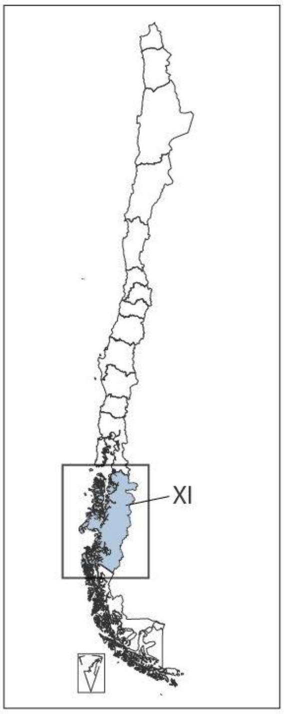


Figure 62: Los Lagos - Chacao Channel inset

8.7 Aysén

8.7.1 Regional overview



XI. Aysén

Chile's Austral region is distinguished by two principal geographic zones: a coastal area in the west with numerous fjords, islands and channels, and an interior zone of Patagonian steppe, to the east of the Southern Andes. The region has just over 100,000 inhabitants (15% of whom live in rural areas) and the principal productive activities are livestock farming, tourism, forestry, mining, aquaculture and fishing. Aysén has no electrical connection with the other regions of Chile (see map at the end of this section) and only one medium-sized electricity grid connecting the areas around Puerto Aysén and Coyhaique. Generation is from a mix of five thermal and four hydroelectric power plants plus one wind farm.

Although not sufficient for large farm deployments, there are specific areas with significant tidal resources in Aysén, which have yet to be studied in detail. Many of Aysén's communities and industries (particularly salmon farms) are found in remote areas and depend on diesel generation for their power requirements which can be doubly expensive due to the large distances which must be covered to supply these sites with fuel. Tidal streams in areas such as Canal Carbunco and Estrecho Elefantes can reach 2 to 3m/s (mean spring peak). Puerto Aguirre and Puerto Raúl Marín Balmaceda could act as local support bases.

Annual average wave energy levels on exposed Pacific coasts are very high and estimated between 87-111kW/m - however these areas are far from demand. Aysén has a very large Pacific coastline (due partly to the numerous islands) and a wide seabed shelf of appropriate depth for mooring devices, but it is unlikely that offshore wave power projects will be developed here in the near future, given the large distances and lack of infrastructure. Melinka port in the north of Aysén receives some swell and wind waves which could make it a suitable location for the development of a smaller wave energy project.

8.7.2 Regulatory framework

The region of Aysén primarily has access to nationally administrated rather than local financial support. The Regional Government of Aysén, supports development studies and infrastructure projects - these are often aimed at supporting isolated and economically deprived areas. Interestingly, Aysén was the first region in Chile to have a grid connected wind farm. Aysén was also the first region in Chile to develop a map of coastline use, which could in the future include marine energy projects.

8.7.3 Research, Development and Innovation

Austral University has a presence in the region through the Centre for Patagonian Ecosystems Research (*Centro de Investigación en Ecosistemas de la Patagonia*, CIEP) which carries out research related to aquatic and terrestrial ecosystems, traditional fishing, sustainable tourism and aquaculture. There is a significant amount of practical marine experience and knowledge available, particularly in aquaculture where there are teams of technical professionals able to survey, consent, design and develop the region´s numerous salmon farms (see maps on following pages and Figure 30 in the RD&I chapter of this report, page 50).

8.7.4 Infrastructure and supply chain

Aysén electricity network is not currently connected to the rest of Chile and has an installed power capacity of just 41MW (0.23% of Chile's total capacity). HidroAysén is an ongoing project which aims to develop 5 hydroelectric plants, 2 in the river Baker and 3 in the river Pascua, with a total installed power of 2,750MW and an annual generation capacity of 18,430GWh. These plants would be connected to the SIC electricity network via a new (possibly subsea) connection[41].

Aysén's regional capital is Coyhaique. Puerto Chacabuco is the main port, which handles a lot of salmon farming activity and could support medium sized marine energy projects.

8.7.5 Energy markets

Figure 63 compares the actual installed generation capacity (including off-grid diesel) in Aysén to the wave and tidal resources in the region. It can be seen that whilst the total resources are very large and many times greater than current energy demand, the technical wave resource is negligible for the selected criteria (see Figure 46, page 90). Tidal projects may be easier to realise and could replace or reduce off-grid diesel generation at certain sites.

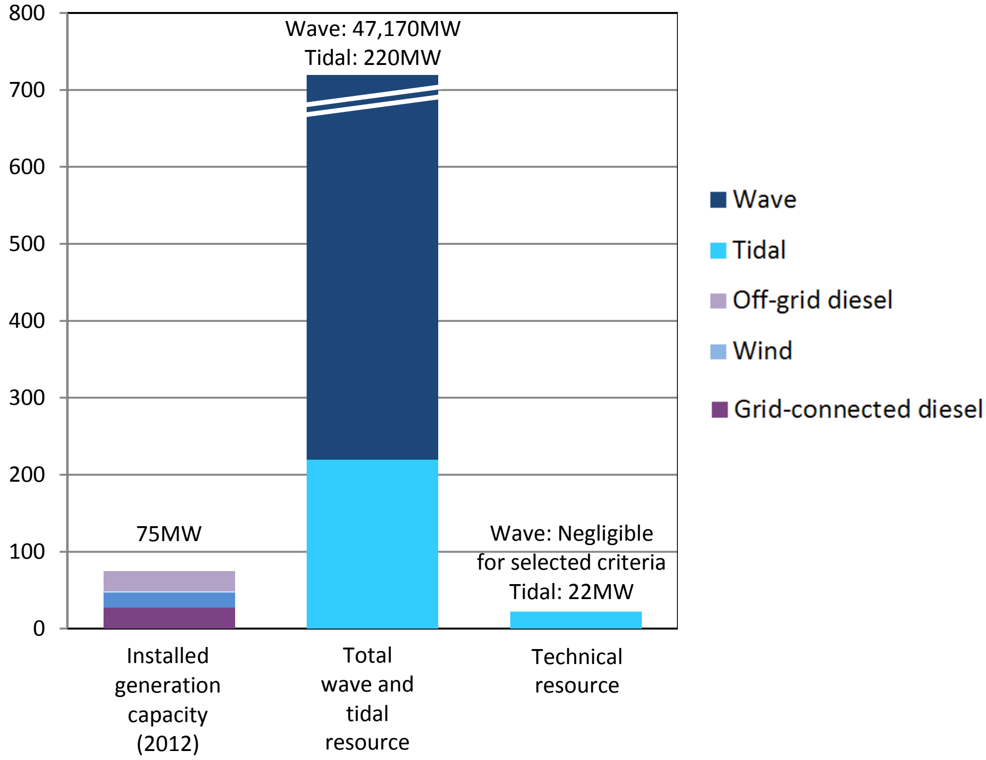


Figure 63: Installed generation capacity compared to marine energy resources (Aysén)

Aysén is the second most important region for aquaculture activities with a total of 490 aquaculture concessions[42]. The concentration of these farms in areas with potentially significant tidal currents can be seen in the map below. There are also a total of 17 fishing coves (mainly in the north of the region) and 14 registered mining sites[43].

[41] http://www.hidroaysen.cl/

[42] http://web.directemar.cl/estadisticas/maritimo/default.htm

[43] http://www.sernageomin.cl/sminera-atlas.php

In the long term with the development of marine energy technology and the planned connection of Aysén to the national grid, it may eventually be possible to harness the enormous offshore wave energy resource in this region, perhaps as part of an offshore "supergrid" connecting this area to centre of energy demand in other parts of Chile and beyond.

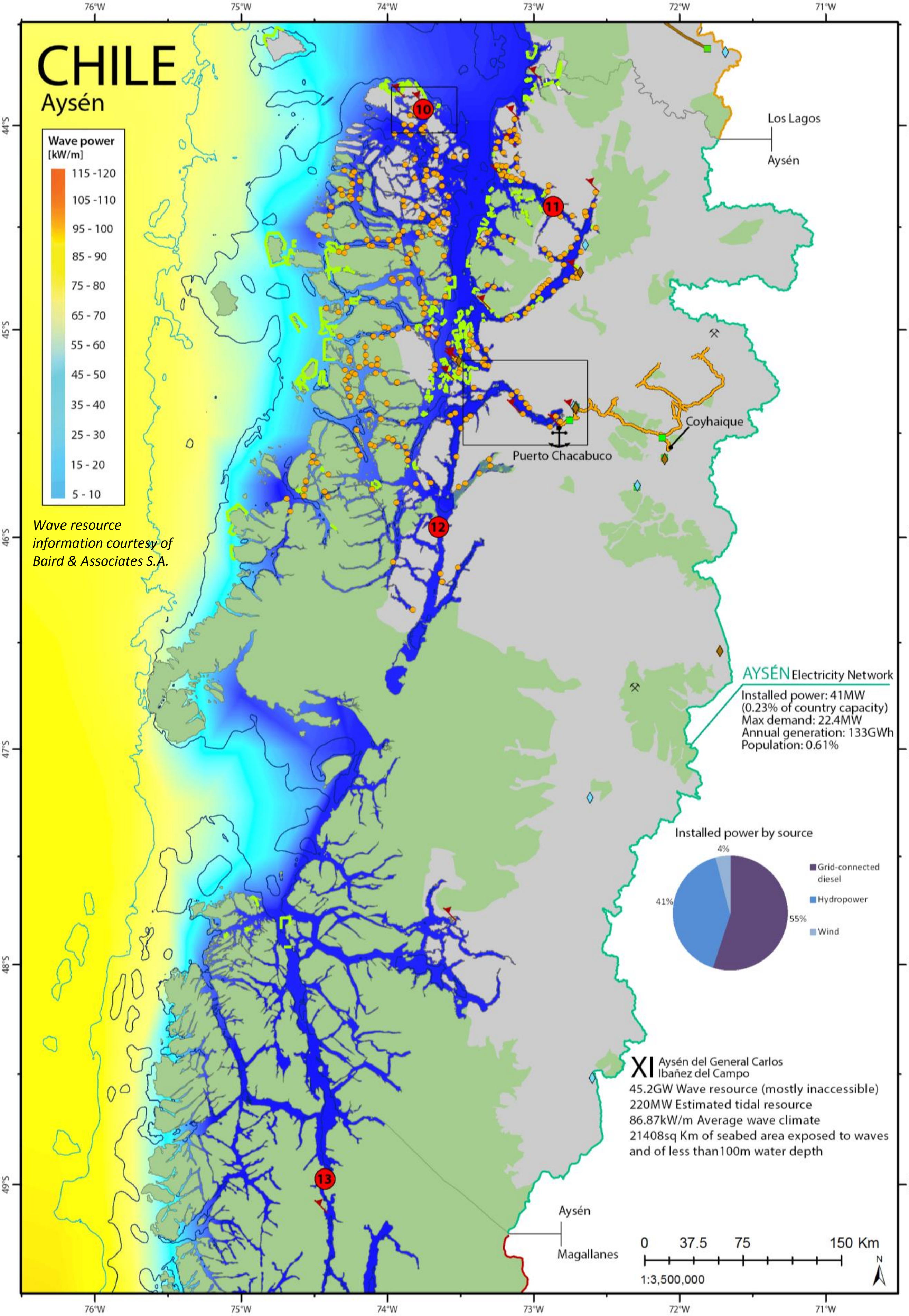
8.7.6 Conclusions - Aysén

Small scale tidal projects for isolated communities and salmon farms would appear to be the most viable development area for marine energy in the region of Aysén for the foreseeable future. A limited number of smaller wave energy projects in the north of the region may also be viable (e.g. Melinka). Much of the support infrastructure for deployments of this scale is already in place as a result of the bourgeoning salmon farming industry.

Recommendation 8-G: Marine energy development in Aysén

The **Regional Government of Aysén** may wish to consider commissioning a study potential for small-scale tidal power projects in the region. This would require some more detailed tidal resource assessment and could consider the feasibility of supplying energy to isolated communities or salmon farms, possibly as part of an integrated renewables package with diesel back-up.

Regional Government of Aysén **Short term**


CHILE
Aysén
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Wave resource information courtesy of Baird & Associates S.A.
76°W
75°W
74°W
73°W
72°W
71°W
44°S
45°S
46°S
47°S
48°S
49°S
Los Lagos
Aysén
Coyhaique
Puerto Chacabuco
10
11
12
13
AYSÉN Electricity Network
Installed power: 41MW
(0.23% of country capacity)
Max demand: 22.4MW
Annual generation: 133GWh
Population: 0.61%
Installed power by source
4%
41%
55%
Grid-connected diesel
Hydropower
Wind
XI Aysén del General Carlos Ibañez del Campo
45.2GW Wave resource (mostly inaccessible)
220MW Estimated tidal resource
86.87kW/m Average wave climate
21408sq Km of seabed area exposed to waves and of less than100m water depth
Aysén
Magallanes
0 37.5 75 150 Km
1:3,500,000
N

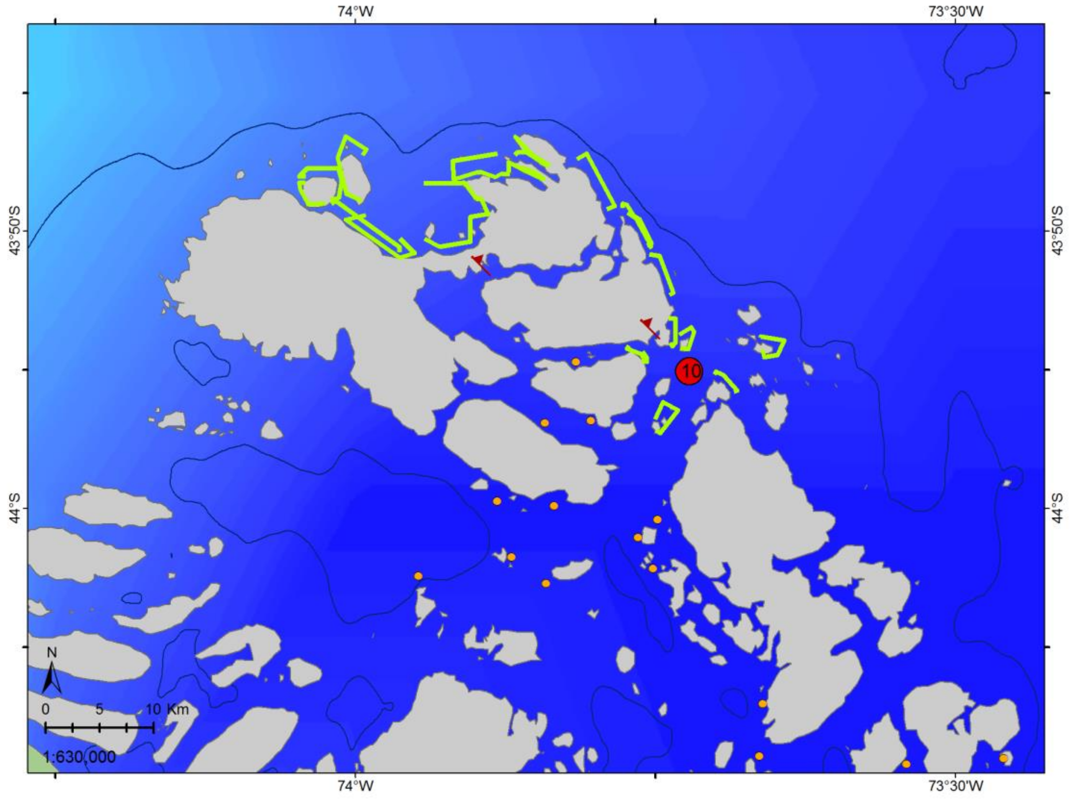


Figure 64: Aysén - Canal Carbunco inset

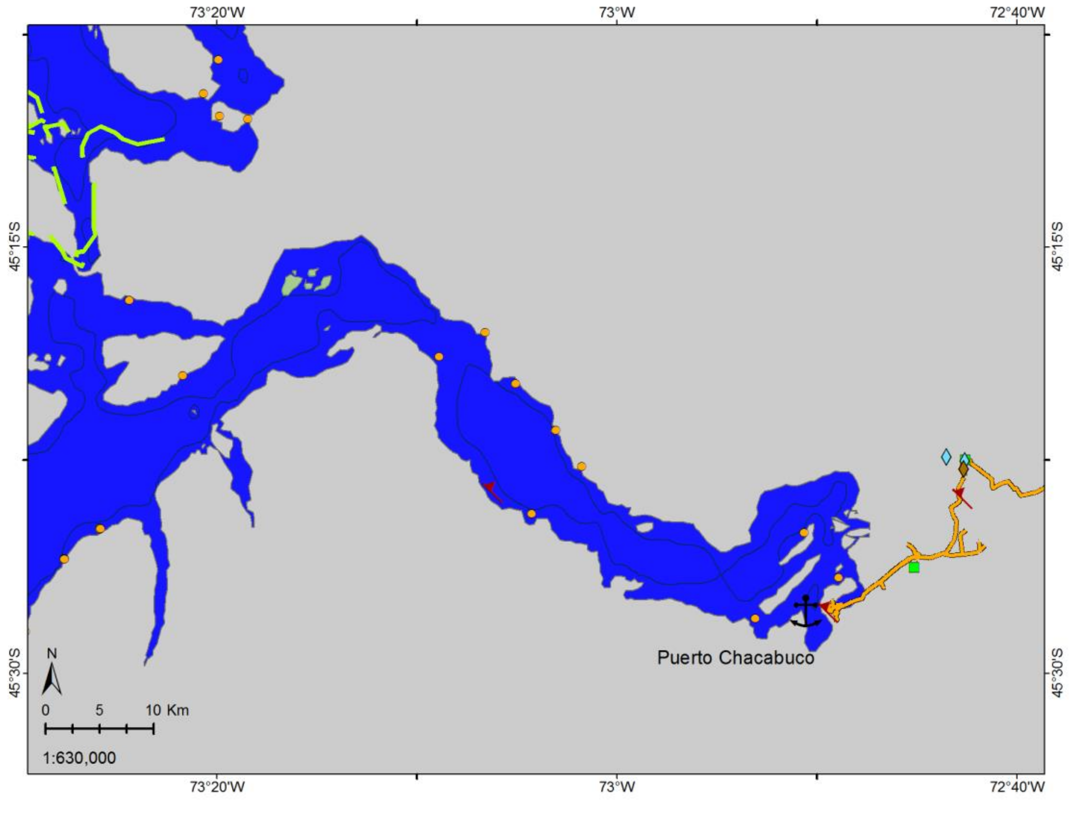
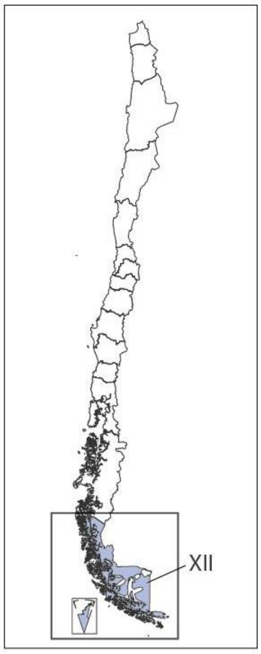


Figure 65: Aysén - Puerto Chacabuco inset

8.8 Magallanes

8.8.1 Regional overview



XII. Magallanes

The Magallanes region is located at the extreme south of mainland Chile and is characterised by fjords, glaciers and Patagonian steppe. Administratively, this region is part of the Magallanes and Chilean Antarctic region, although only mainland Chile is considered here. The population in Magallanes is almost 160,000, 1% of Chile's population. The main activities in the region are livestock, mining, oil and gas, fishing and tourism. The region is separated from the rest of Chile by hundreds of miles of ice fields and can only be reached by air or sea from the rest of Chile – or by land through Argentina.

The Magellan Strait holds Chile's greatest tidal resource, which is concentrated where the strait tightens at the First and Second Narrows and tidal current speeds reach 4m/s (8 knots) or more. The total theoretical tidal resource is estimated to be greater than 3,500MW although further detailed studies are required to make an accurate estimate. The regional capital of Punta Arenas on the shores of the strait could provide a market for this power. There are also important tidal streams in the Fitzroy Channel, Beagle Strait and many other smaller sites which have also yet to be studied in detail. Tidal range is the region is approximately 2m but can reach 9m in some locations (i.e. Punta Delgada in the First Narrows).

The wave resource on exposed Pacific coasts is extremely high (111-120kW/m) but as in Aysén, these areas are so exposed and remote that development of this resource is not foreseeable at present. Smaller scale wave power projects using the consistent wind swells in areas such as Seno Otway or the wider parts of the Magellan Strait may be viable.

Generation in the Magallanes electricity networks comes primarily from gas (83%) and diesel (14%). There is also three-turbine wind farm at Cabo Negro near Punta Arenas.

8.8.2 Regulatory framework

About 70% of the land area of the Magallanes region is protected, so appropriate environmental impact assessments and mitigation will be a priority for any marine energy project in this region. The ongoing development of a regional land use plan (PROT by its initials in Spanish) by the regional government of Magallanes provides an opportunity to identify appropriate marine energy sites and projects.

The Magallanes region benefits from a number of different tax breaks and incentives. For example, the Austral Plan provides "First Category Tax" exemption of up to 32% for investment in fixed assets. Similarly, the Tierra del Fuego law provides "First Category Tax" exemption until 2035 in Primavera province. These measures have been effective in promoting the creation of new industrial clusters and could be used to support the development of the marine energy supply chain, including device or component manufacturing. The Magellan Development Fund (FONDEMA by its initials in Spanish) also supports renewable energy and energy efficiency projects.

8.8.3 Research and development capability

CEQUA (*Centro de Estudios del Cuaternario, Fuego-Patagonia y Antártica*) is a local research institute conducting research on the potential environmental impacts of marine energy development in Magallanes. The University of Magallanes runs undergraduate and postgraduate engineering courses, with a focus on local issues and in some cases local wind energy projects.

There is also some private sector RD&I activity in Magallanes, for example Alakaluf Ltd. (a partner to this project), an oceanographic company based in Punta Arenas which has surveyed some of the most attractive wave and tidal power sites in the region.

8.8.4 Infrastructure and supply chain

Generation, transmission and distribution in Magallanes are controlled by the same company, EDELMAG (unlike in the SIC and SING, where these functions are separated). There are four separate electricity networks in Puerto Natales, Punta Arenas, Porvenir and Puerto Williams with no electrical connections between these areas or to other regions. The Magallanes electrical system is defined under Chilean law as a medium sized system and as such does not fall under the same regulations or targets as regards the integration of non-conventional renewable energy (NCRE) or smaller generators.

Punta Arenas is the largest settlement in Magallanes, with a population of around 120,000 people. The city has an ASMAR shipyard as well as other workshops and facilities including six piers. There is a wide range of vessels, tugs, barges and cranes available as well as qualified marine crew and technical personnel, for example in electronics or marine mechanics.

The development of the oil and gas projects in the Magellan Strait has built up experience in the installation and repair of offshore structures, pipes and cables. Many of these assets are no longer operational and have the potential to be re-used for marine energy, for example as support bases or substation locations for tidal projects.

8.8.5 Energy markets

Punta Arenas is a regional hub with a sizeable market for power. There are isolated communities in Puerto Edén, Río Verde, Punta Delgada and Puerto Williams amongst others.

There are a total of 42 aquaculture concessions in Magallanes[44] as well as at least ten fishing coves, mainly near Punta Arenas and Puerto Williams and a few isolated areas further north. There are 25 registered mining sites[45].

The development of innovative energy uses such as electricity for transport or the export of power as manufactured goods or hydrogen may be worth considering, given the lack of grid or demand in many areas and the size of the available resources (Figure 66).

[44] http://web.directemar.cl/estadisticas/maritimo/default.htm

[45] http://www.sernageomin.cl/sminera-atlas.php

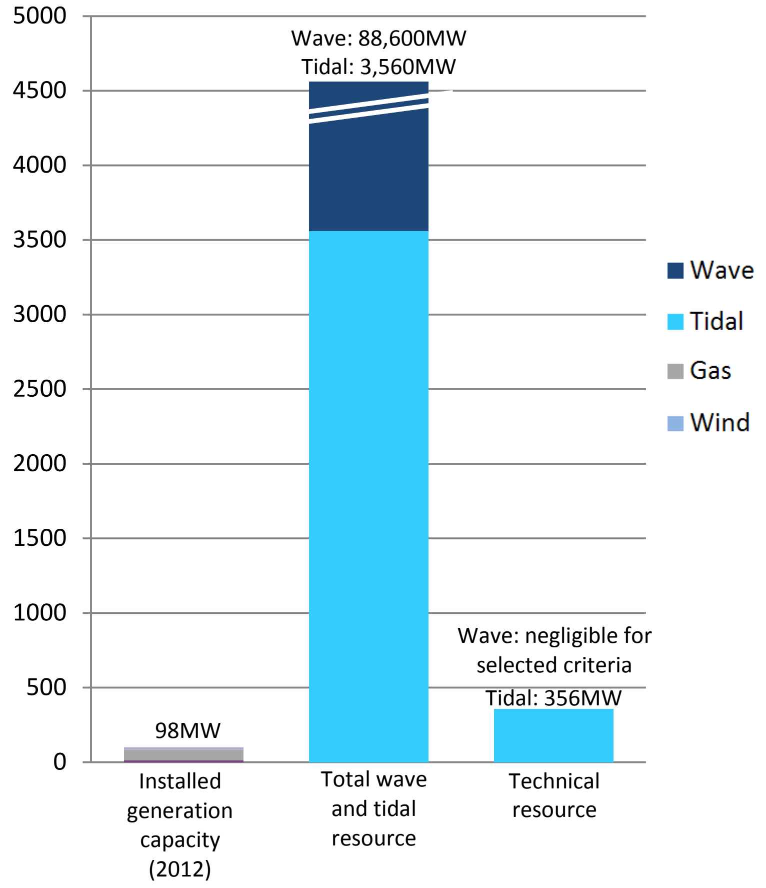


Figure 66: Installed generation capacity compared to marine energy resources (Magallanes)

Figure 66 shows that current electricity demand in Magallanes is dwarfed by the available marine energy resources. Other energy demands such as for transport and heating could also be met by marine (and particularly tidal) energy, if appropriate technology and systems could be put in place (Recommendation 8-J).

8.8.6 Conclusion - Magallanes

The Magellan Strait is the most important tidal stream in Chile and a prime location for large tidal power projects. There are other opportunities for marine energy development too. The tide flows strongly through the Beagle Channel where Puerto Williams is reliant on diesel generation, and the ideal, sheltered conditions of the Fitzroy tidal channel north of Punta Arenas are relatively close to a new mining project.

Although the offshore wave energy resources in the Magallanes region are unlikely to be developed in the foreseeable future, there are a number of areas which are exposed to consistent wind waves (such as the wider parts of the Magellan Strait or in Seno Otway) where wave power projects may be possible in the short to medium term – these have yet to be evaluated and are not shown in Figure 66. Marine energy projects on the Pacific coast of Magallanes may one day be possible but are remote at present.

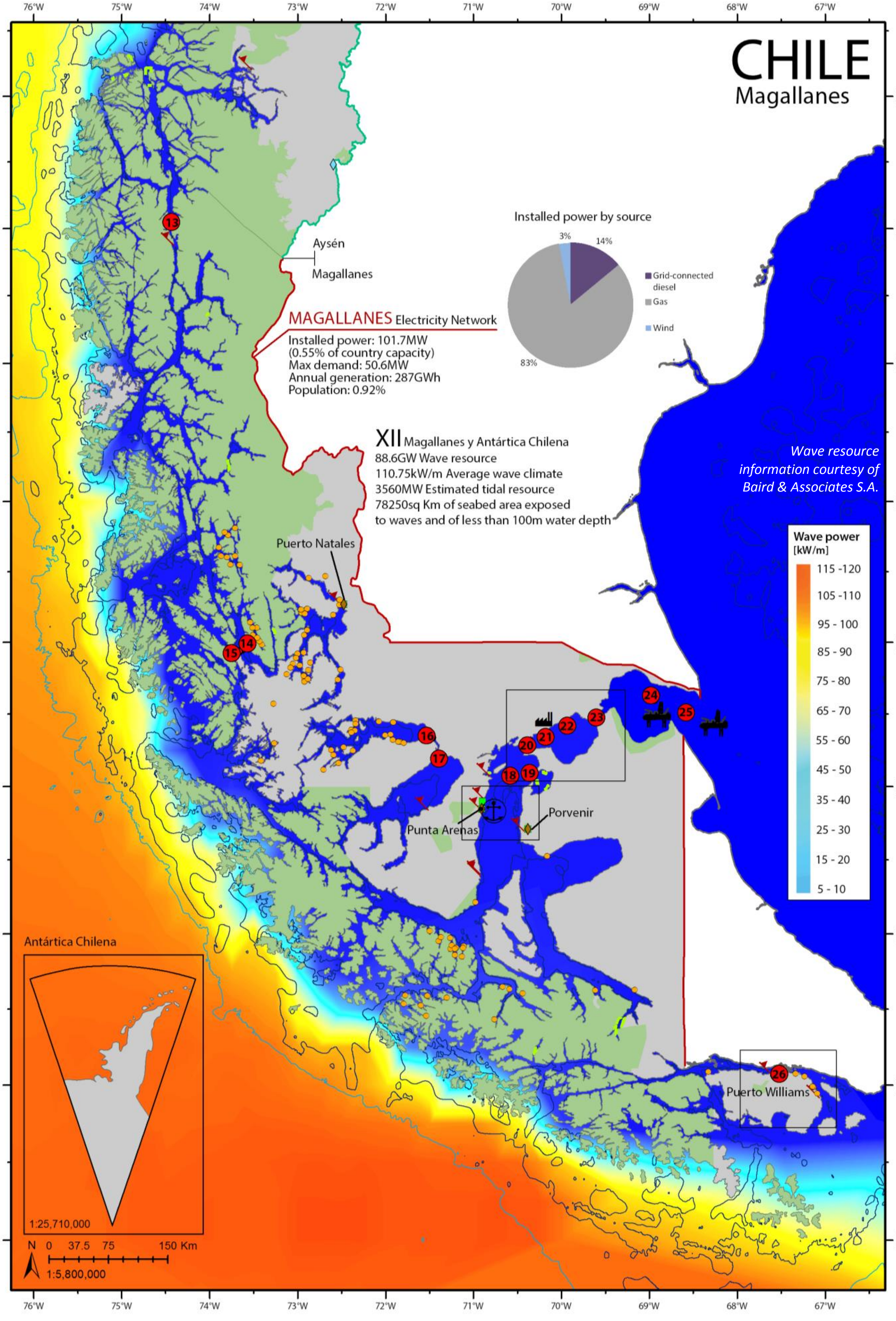
More research is required to quantify the available and viable marine energy resources in Magallanes. This could inform the development of a strategic plan for public and private sector organisations to promote and advance the incorporation of marine renewable energy in the Magallanes region as a source of environmentally friendly power and local industry development.

Recommendation 8-H: Marine energy development in Magallanes

The **Regional Government of Magallanes** may wish to consider commissioning a study of the wave and tidal power potential in the region, to inform the development of a strategic plan for marine energy development. This could include:

- Identification of the most promising marine energy sites in coordination with the regional coastline use commission (**CRUBC**).
- Consideration of how projects could be constructed to make use of the regional tax breaks and incentives e.g. by manufacturing locally.
- Consideration of alternative energy uses such as direct use by industry ("export of energy as manufactured goods or hydrogen"), electrification of heating or transport systems, etc.

Regional Government of Magallanes **Short term**


CHILE
Magallanes
Installed power by source
3%
14%
83%
Grid-connected diesel
Gas
Wind
Aysén
Magallanes
MAGALLANES Electricity Network
Installed power: 101.7MW
(0.55% of country capacity)
Max demand: 50.6MW
Annual generation: 287GWh
Population: 0.92%
XII Magallanes y Antártica Chilena
88.6GW Wave resource
110.75kW/m Average wave climate
3560MW Estimated tidal resource
78250sq Km of seabed area exposed
to waves and of less than 100m water depth
Wave resource information courtesy of Baird & Associates S.A.
Wave power [kW/m]
115 -120
105 -110
95 - 100
85 - 90
75 - 80
65 - 70
55 - 60
45 - 50
35 - 40
25 - 30
15 - 20
5 - 10
Puerto Natales
Punta Arenas
Porvenir
Puerto Williams
Antártica Chilena
1:25,710,000
N 0 37.5 75 150 Km
1:5,800,000
76°W
75°W
74°W
73°W
72°W
71°W
70°W
69°W
68°W
67°W
48°S
49°S
50°S
51°S
52°S
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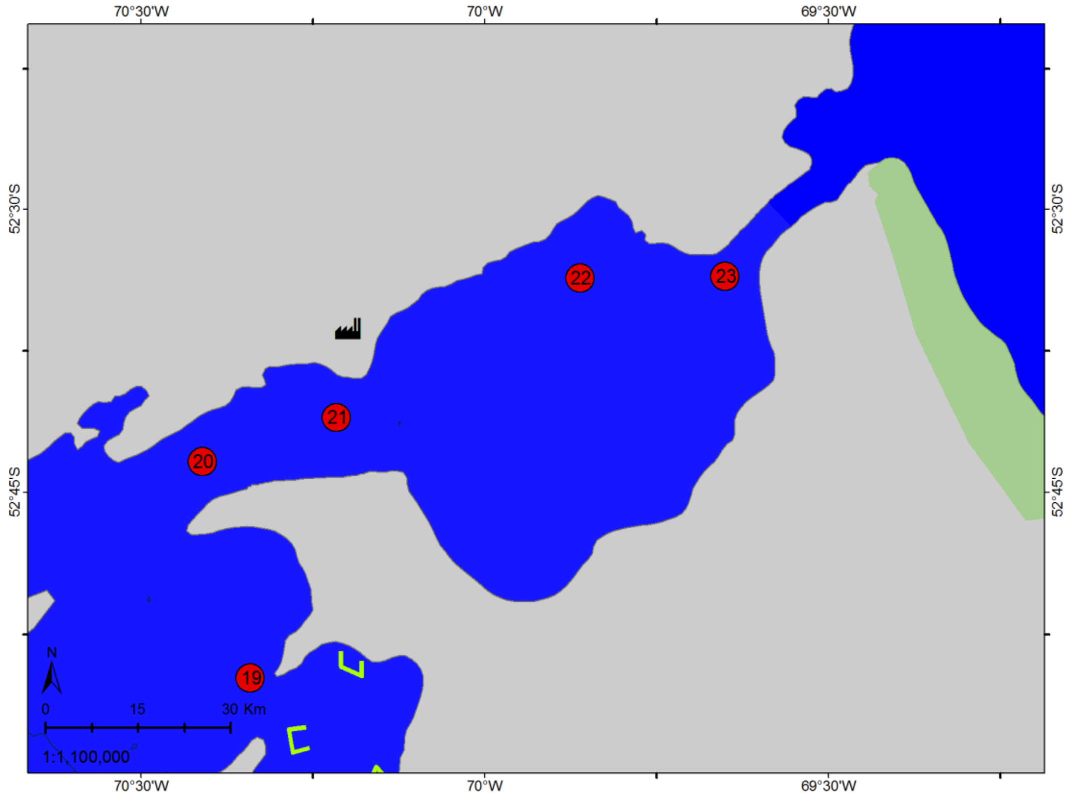


Figure 67: Magallanes - Magellan Strait inset

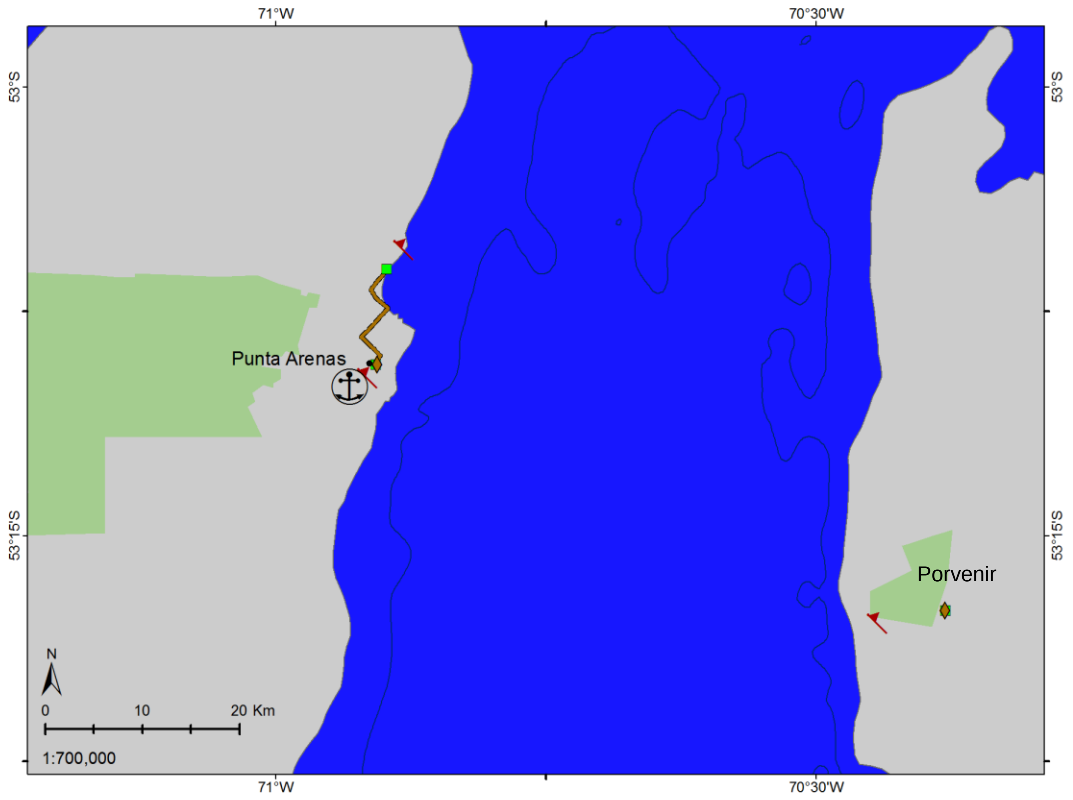


Figure 68: Magallanes - Punta Arenas inset

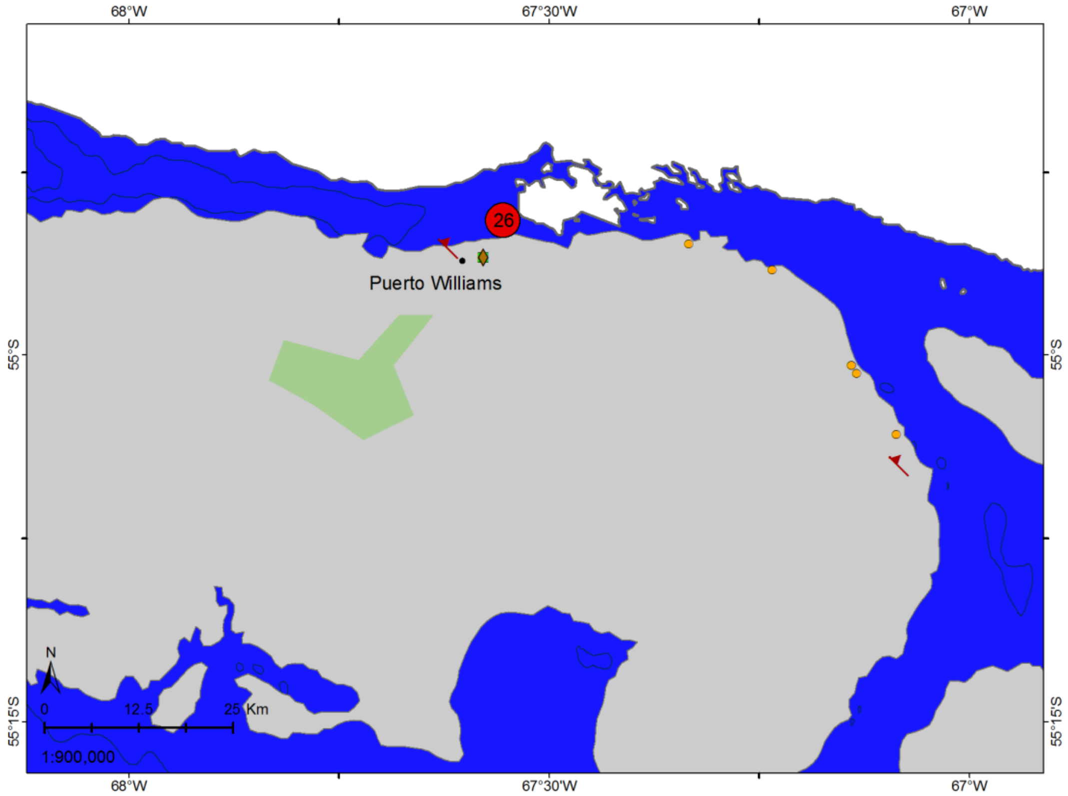


Figure 69: Magallanes - Puerto Williams inset

8.9 Conclusions from regional analysis

The preceding analysis has demonstrated the many and varied opportunities for marine energy development throughout Chile. It is clear that marine energy policy needs to be tailored to the particular requirements, challenges and opportunities in each region. Table 17 gives a summary of the marine energy development potential in the different marine energy regions.

Table 17: Suggested regional priorities for marine energy development

Key:	Good potential	Some potential	Little or no potential

	Norte Grande & Chico	Centro & Centro Sur	Los Lagos	Aysén	Magallanes	Offshore islands
Technology						
Small scale and off-grid tidal projects	Little or no potential	Little or no potential	Good potential	Good potential	Good potential	Some potential
Multi-MW tidal projects and farms	Little or no potential	Little or no potential	Good potential	Some potential	Good potential	Little or no potential
Small scale and off-grid wave projects	Good potential	Good potential	Good potential	Some potential	Some potential	Good potential
Multi-MW wave projects and farms	Good potential	Good potential	Good potential	Little or no potential	Little or no potential	Little or no potential
Device manufacture	Some potential	Good potential	Some potential	Some potential	Good potential	Little or no potential
Energy markets						
Electrical grid and direct industrial use	Good potential	Good potential	Good potential	Some potential	Some potential	Some potential
Desalination / water pumping (mining)	Good potential	Some potential	Little or no potential	Little or no potential	Little or no potential	Little or no potential
Community desalination	Good potential	Some potential	Little or no potential	Little or no potential	Little or no potential	Good potential
Community energy	Good potential	Good potential	Good potential	Good potential	Good potential	Good potential
Salmon farms	Little or no potential	Little or no potential	Good potential	Good potential	Good potential	Little or no potential

Recommendation 8-I: Identification and designation of the best marine energy sites (Regional Governments)

Regional Governments may wish to consider commissioning studies of the marine energy potential of their respective regions, to identify and designate the most promising sites for development, in coordination with the regional coastline use commissions (**CRUBCs**)

Regional Governments / CRUBCs **Short term**

Recommendation 8-J: Regional assessments of marine energy development potential

Chile´s **Regional Governments** and the **Subsecretary of Regional Development** may wish to consider including an assessment of the regional potential for marine renewables to provide energy and/or water for remote communities as part of the strategies for remote communities that they are required to develop.

Note: Some regions are already considering a collaborative scheme with local universities, funded by CORFO´s Innovation for Competitiveness (FIC) fund.

Regional Governments / Sub-secretary of Regional Development **Short term**

Recommendation 8-K: Regional marine energy development programmes

The planned marine energy **ICE** may wish to consider developing regional marine energy development programmes in coordination with regional institutions.

ICE and regional institutions **Short term**

Case study 8-A: Creating jobs on the periphery (Orkney, UK)

Company formation numbers in Orkney have seen a dramatic increase over the past few years (Duport Associates Ltd, 2012). There were 17 companies formed in Orkney during the first half of 2009, but by the first half of 2012 this number had more than doubled to 40 - beating any other half year on record. The report also shows a significant rise in net company growth when comparing 2009 and 2012, suggesting that the past three years have seen region's economy grow and strengthen.

The economy of these relatively isolated islands has long been rooted in agriculture, thanks to extremely fertile soil and a rich farming heritage. However, Orkney is also becoming a leader in renewable energy, particularly wind, wave and tidal power. Naming data included in the Duport report suggests that new companies are forming in this industry, with "wind", "power" and "renewables" all appearing amongst the top ten most popular words used in new company names between June 2011 and June 2012.

One single wave energy developer, Aquamarine Power, has spent more than £5 million directly in this peripheral community and has employed more than 50 local businesses. There are currently 14 technology developers actively engaged in Orkney.

One study (Aquamarine Power, 2009) estimates that a 200MW wave farm in Orkney would create £38.3 million gross value added (GVA) to the Orkney economy and would create 1,305 job years, equating to an average of 52 additional jobs each year in Orkney over the 26 year lifetime of the project. This compares with six jobs each year in the rest of Scotland for the same project – demonstrating the direct and lasting economic benefits of ocean energy development in remote areas.

9 Possible growth scenarios

This chapter of the report briefly reviews the philosophy adopted in the development of the Chilean Government´s marine energy strategy, before investigating the potential effects that the chosen strategy might have on the growth of marine energy in Chile. This growth is of course not purely dependent on government strategy, although this can have a very significant effect, and the assumptions made are stated.

9.1 Marine energy strategies

The 2012 report *"Marine energy development – taking steps for developing the Chilean resource"* by Errazuriz and Associates and the University of Edinburgh (E&A/UoE) outlined two marine energy strategies that Chile could implement:

A. A ***development strategy*** *whereby the country would provide support to the sector in order to take an active role in the development of marine energy technologies and reap the associated economic benefits.*

B. A deployment strategy whereby the country would wait for technology to be developed abroad before purchasing and deploying the devices to take advantage of the benefits associated with exploiting the country's attractive resources.

The Chilean Government has since stated its preference for pursuing a **development strategy** (see Chapter 3, page 12) and has already made progress towards this objective, particularly with the announcement of the planned pilot projects and ICE. For this reason scenarios resulting from a pure deployment strategy are not covered in this report.

Although the support planned to date for marine energy in Chile is more than would be provided under a deployment strategy, it is not considered sufficient at this stage to constitute a full development strategy, and so the term **deployment plus strategy** is used to describe the scenario resulting from current policy initiatives announced to date.

It is believed that further government support would be required for a **development strategy** to be fully realised. Suggestions are made as to what the key elements of this might be - these constitute the assumptions for the evaluation of this second scenario.

It would also be possible for Chile to take an even more active role in marine energy development by providing levels of support to the sector which are similar to those seen in some European countries. This would be an **accelerated development strategy**.

The **deployment plus strategy** scenario therefore is what could result from the successful implementation of current and planned policies and support measures. The **development strategy** scenario would require more support from the Chilean Government but is believed to be technically and politically realistic, whilst the **accelerated development strategy** scenario is believed to be politically optimistic but technically realistic.

It should nevertheless be noted that all of these options are hypothetical scenarios chosen to demonstrate the potential influence of government policy on marine energy development. It is clearly not possible to predict how future developments will take place with a high level of accuracy.

What is clear is that some form of government support at the pre-commercial stage can increase installation activity and hasten the onset of commercial projects, as well as strengthening Chilean capacities in the interim.

9.2 Assumptions

In summary, the three potential scenarios and their associated assumptions are:

Deployment plus strategy – In this scenario, the planned centre of excellence, pilot projects and proposed regulatory changes are implemented successfully, but no further financial support for the installation of wave and tidal devices is announced. This could potentially limit activity in the sector between the end of the pilot projects and the advent of commercial projects. Some transitional projects would still be realised where there was sufficient industry and community support. Specific milestones that are envisaged would be:

- Wave and tidal pilot projects are installed by 2016;
- Some limited growth in small-scale, market niche and industrially-supported marine energy projects is seen;
- Moderate growth of tidal farms from the early to mid-2020s;
- Moderate growth of wave farms from the mid to late-2020s;

- *This is based on the state of marine energy policy in Chile as of the end of 2013.*

Development strategy – activities in above scenario are completed. Additional support measures for small scale, remote and market niche projects are introduced in the short term, for example, by the government taking office in March 2014. Finally, additional support for the first pre-commercial wave and tidal farms (say 10 to 30MW capacity) would be made available by 2020. Specific milestones that are envisaged would be:

- Wave and tidal pilot projects are installed by 2016;
- Growth in small-scale, market-niche and industrially supported projects is strong;
- Installation of the first pre-commercial farm(s) around the year 2020 is a catalyst for:
    - Strong growth of tidal farms from the early 2020s
    - Strong growth of wave farms from the mid-2020s

- *This would require further support for small-scale and market niche projects to be made available in the short term, and limited support for pre-commercial farms to be provided in the medium term (for example by 2020).*

Accelerated development strategy – this would be reliant upon a substantial market-pull incentive being introduced which is sufficient to realise multiple grid-connected wave and tidal farms as well as small scale, remote and market niche projects in the short term. Specific milestones that are envisaged would be:

- Wave and tidal pilot projects are installed by 2016;
- Growth in small-scale, market-niche and industrially supported projects is strong;
- Multiple pre-commercial wave and tidal farms are installed;
- Very strong growth of tidal farms from the early 2020s;
- Very strong growth of wave farms from the mid-2020s;

- *This would require a level of support (i.e. market intervention) for marine energy which is similar to that seen in countries such as the UK or France.*

In general it was also assumed that:

- The rate of marine energy development worldwide will lead to cost reduction on the timescales shown in Figure 43. This would lead to grid connected tidal energy being competitive with other forms of grid connected renewables in Chile by the early to mid-2020s, and grid connected wave energy competitive by the mid to late 2020s.
- The cost of generation from diesel will rise as shown in Figure 32, and the cost of transport will add 27% to this cost in remote areas.
- There will be a moderate (below the current trend) rise in the cost of electricity in the Chilean SIC and SING networks. This would be reflective of the planned integration measures to reduce these costs being somewhat off-set by rising commodity prices.

9.3 Growth estimates

For each of the three strategy scenarios (**deployment plus**/**development**/**accelerated development**) an estimate of likely installation rates was carried out for the following types of projects:

- **Small-scale and off-grid:** wave or tidal power projects of tens or hundreds of kilowatts capacity (kW), competing with diesel generation to supply fishing coves, salmon farms or isolated communities with power and/or drinking water. It is envisaged that with current government support measures, some such projects may be viable in the short term for tidal and medium term for wave, but that increased levels of government support as part of a development strategy would accelerate this.
- **Pilot project:** the two proposed wave and tidal power pilot projects of approximately 1MW total capacity each, although multiple devices may make up this capacity.
- **Pre-commercial farm:** deployments of multiple devices backed by additional government or industrial support i.e. expansion of pilot projects.
    - **Deployment plus strategy:** no pre-commercial farms
    - **Development strategy:** 15MW total (wave and tidal) by 2020
    - **Accelerated development strategy:** 30 or 50MW total by 2020

  Note: these pre-commercial farms could be water pumping or desalination projects.
- **Mining: water pumping/desalination:** wave power projects supplying the mining industry with desalinated or untreated seawater[46]. Under a **development strategy**, a 2MW pilot project would be established in the short term and supported to grow to 20MW in the medium term before becoming commercial. In an **accelerated development strategy** scenario, more support would be given in the short term.
- **Commercial grid-connected:** wave or tidal power projects which are realised without significant government support.

A breakdown of the estimates made for the development strategy scenario is presented below, followed by a comparison of the results from all three scenarios.

[46] Tidal power does not lend itself to direct water pumping or desalination in the same way as wave power, either technologically (many wave power devices are hydraulic; most tidal power devices are not) or geographically (water supply is a problem in the north of Chile; the tidal sites are in the south) Nonetheless, sites near mines such as the Fitzroy Channel could supply power.

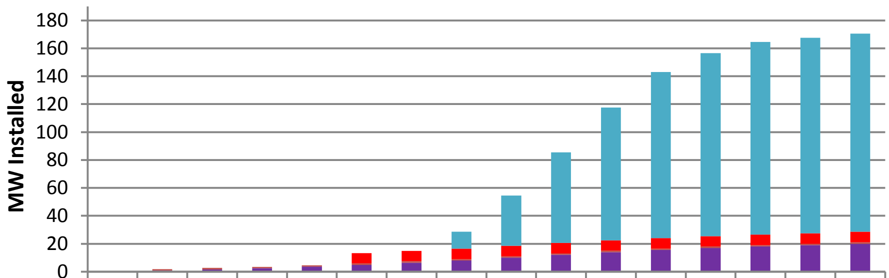
9.3.1 Potential growth of tidal power

As mentioned elsewhere in this report, tidal power technologies are considered to be more developed and to have lower generation costs than wave power technologies. The tidal power technology market is more consolidated. Greater and more regular power production from these devices is being achieved than from wave power devices so far.

Aside: This can be understood partly by comparing working principles. All successful tidal power devices make electricity from rotary turbines in flow. In this sense they are conceptually simple and similar, to some extent, to wind turbines. Indeed tidal power has been helped by technology transfer from that industry. The challenge of wave power is to capture energy from low-speed and high-force oscillations (waves) rather than flow, which is a more complex problem with an apparently more diverse range of power conversion solutions.

There are however a relatively limited number of suitable sites for tidal power developments in Chile. The Chacao Channel for example is one of Chile´s most important tidal sites, and is estimated to have around 800MW of total resource. As an approximation, typically 10% to 15% of such a resource may be economically extractable (see Figure 25, page 39), and so after around 80 to 120MW is installed the site may effectively be saturated. As tidal sites are developed, the extent of the total tidal potential in Chile will therefore become limiting and, it is likely that there will be a slowdown in tidal installation activity (Figure 70). The maximum amount of tidal power capacity that could be installed in Chile is unclear and requires further resource assessment and site investigation work to define but could be greater than is shown here, particularly if a market can be found for power from sites such as the Magellan Strait (e.g. through electrification of transport or hydrogen production) or for the many smaller sites in the southern regions of Chile.

It is probable that tidal power will be commercialised before wave power, and that tidal power installation activity will outstrip wave power installation activity for at least the first half of the 2020s. Nonetheless the fact that the total Chilean wave resource is approximately one hundred times greater than the tidal resource (Baird & Associates, 2012) may well provide added impetus to the wave sector in Chile. Indeed in pure resource terms it could be argued that the case for the Chilean Government to support a pre-commercial tidal power farm is less critical than it is for supporting pre-commercial wave power.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Commercial grid-connected	0	0	0	0	0	0	0	12	36	65	95	119	131	138	140	142
Pre-commercial farm	0	0	0	0	0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Pilot project	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Small-scale and off-grid	0.4	0.8	1.6	2.4	3.6	4.8	6.4	8	10	12	14	15.5	17	18	19	20

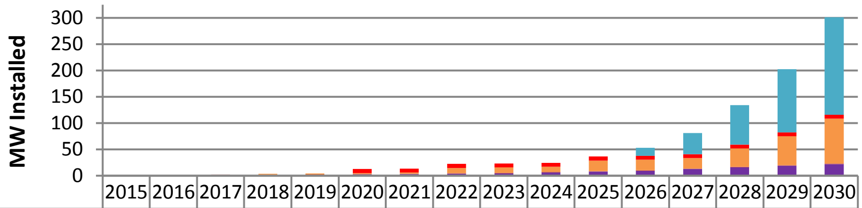
Figure 70: Potential installed tidal power capacity under a development strategy

Figure 70 shows the potential growth in tidal power capacity under a **development strategy** scenario. Equivalent growth estimates were also made for the **deployment plus** and **accelerated development strategy** scenarios, based on the assumptions listed. The total marine (wave plus tidal) figures for each scenario are presented in Figure 73.

9.3.2 Potential growth of wave power

Because of the size of Chile´s wave resource as well as the fact that wave energy devices can be installed in multiple locations (e.g. offshore/near-shore/coastal), the growth of wave power in Chile will not be limited by lack of sites in the same way as for tidal power. However for the reasons given above, it is likely that wave power will take longer to commercialise. There is a greater opportunity for Chile to play a role in wave power technology development than for tidal and the argument for government support is stronger.

Once wave power is commercially competitive, growth in Chile is likely to be rapid. Maximum annual installation rates of 100 MW have been assumed here, but this could be higher if sufficient demand exists.



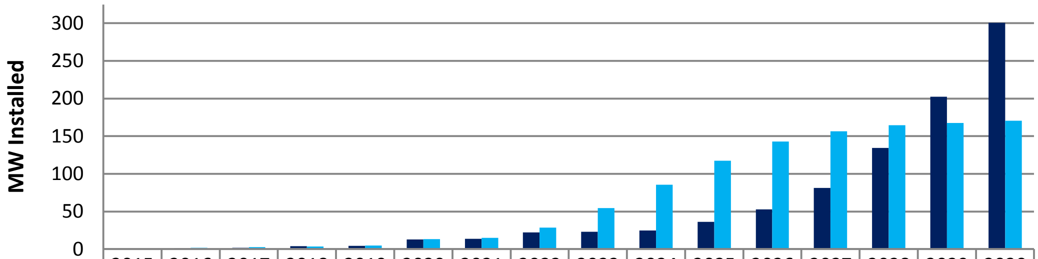
	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Commercial grid-connected	0	0	0	0	0	0	0	0	0	0	0	15	40	75	120	185
Pre-commercial farm	0	0	0	0	0	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5	7.5
Mining: water pumping/desal.	0	0	0	2	2	2	2	10	10	10	20	20	20	35	55	85
Pilot project(s)	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
Small-scale and off-grid	0.1	0.3	0.7	1.1	1.5	2.3	3.1	3.9	4.7	6.3	7.9	9.5	12.7	15.9	19.1	22.3

Figure 71: Potential installed wave power capacity under a development strategy

Figure 71 shows the potential growth in wave power capacity under a **development strategy** scenario. Equivalent estimates were also made for the **deployment plus** and **accelerated development strategy** scenarios based on the assumptions listed. Total marine (wave plus tidal) capacity figures for each scenario are presented in Figure 73.

9.3.3 Wave and tidal power growth comparison

Combining the estimates above enables a comparison of potential growth in wave and tidal power installed capacity. Figure 72 demonstrates the probable occurrence of initial strong growth in tidal power being overtaken by wave power once these projects become commercially viable.



	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
WAVE	0.1	1.3	1.7	4.1	4.5	12.8	13.6	22.4	23.2	24.8	36.4	53	81.2	134.4	202.6	300.8
TIDAL	0.4	1.8	2.6	3.4	4.6	13.3	14.9	28.5	54.5	85.5	117.5	143	156.5	164.5	167.5	170.5

Figure 72: Comparison of potential growth in wave and tidal power (development strategy)

9.4 Conclusions – possible growth scenarios

Combining the wave and tidal growth estimates for each of the three scenarios gives the values for total forecast marine energy capacity shown in Figure 73 below. In all of the scenarios considered, a slow-down in tidal power installation activity was compensated for by an increase in wave power installations, resulting in an overall increase for marine energy capacity.

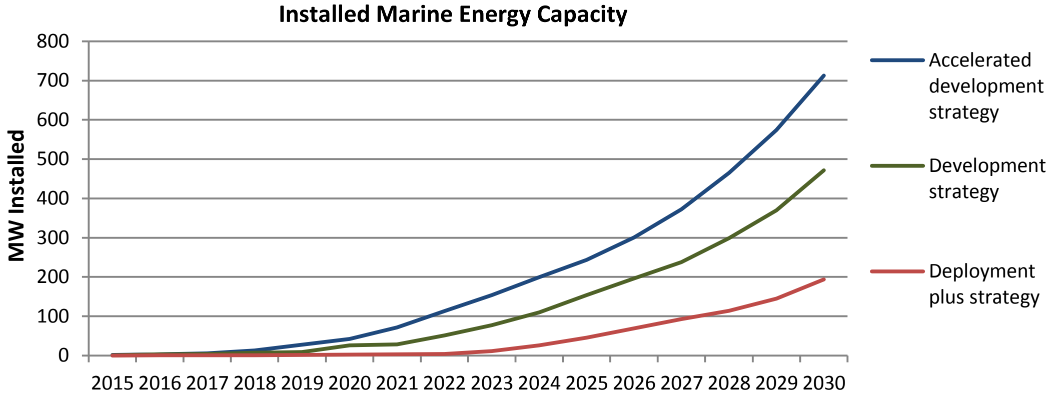


Figure 73: Total marine energy (wave plus tidal) capacity scenarios

The evaluations made suggest that with current and planned levels of support for the marine energy sector (**deployment plus strategy**), growth in installed marine energy capacity could be low until the early 2020s and modest thereafter. The total installed marine energy capacity in Chile could reach 200MW by 2030 in this scenario.

An increase in support to maintain activity in the marine energy sector in the short term and support the first pre-commercial farms in the medium term could constitute a full **development strategy** and in this scenario the installed marine energy capacity in Chile by 2030 could be in excess of 450MW by 2030.

Finally, if there was a political or industrial will for Chile to take a strategic position on marine energy and support multiple pre-commercial farms, this could constitute an **accelerated development strategy** which could lead to rapid and early growth in the marine energy sector and perhaps 700MW of installed marine energy capacity by 2030.

Whilst the three scenarios are hypothetical and would in reality be influenced by changing external factors, they demonstrate possible effects of the Chilean Government´s marine energy strategy on the growth of the industry. It is well established that strong government support at the pre-commercial stage can stimulate technology and supply chain development, and that this encourages earlier and more rapid adoption of these technologies once they become commercially viable. A relatively modest amount of government support can also leverage significant amounts of private investment. It is worth noting that similar effects to those shown could also be achieved by increased industry support, if companies were willing to make the long-term investments needed.

The two additional sections below provide a sense-check of these scenarios against other relevant data, and an investigation of the jobs and investment that the different scenarios could bring.

9.4.1 Comparisons with historic growth in other renewables and forecasts for marine energy in the UK

Figure 74 compares forecast growth in installed marine energy capacity from the three development scenarios to historic growth in other forms of renewable energy in Chile and growth forecasts for marine energy in the UK.

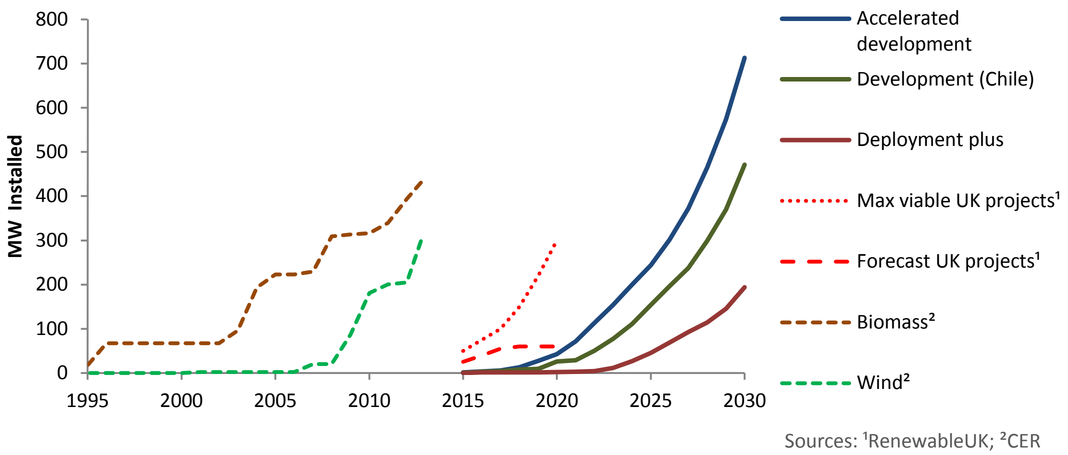


Figure 74: Comparison with past Chilean experience and UK forecasts

It is clear that similar rates of growth to those proposed in this report have already been seen in other renewables in Chile and are expected for marine energy in the UK.

Recommendation 9-A: Forecasting and tracking growth of marine energy

It would be beneficial to create a more detailed growth model for marine energy in Chile which could be linked to the proposed cost of energy study (Recommendation 5-B, page 41) to arrive at the most realistic estimations of future growth.

The results of this growth model could support and be published alongside the proposed regular updates of marine energy strategy by an independent strategy review group (Recommendation 4-P, page 30) as well as the usual activities of the **Ministry of Energy** and **CER**.

Ministry of Energy / CER / Strategy review group **Ongoing**

9.4.2 Jobs and investment

Each MW of installed marine energy can also be considered to represent a number of jobs created and an associated level of monetary investment. As summarised in the 2012 Marine Energy Development report for Chile (E&A/UoE), a number of different organisation have made estimates of how many jobs would be created by the marine energy industry. In 2010 The European Ocean Energy Association estimated that 10 to 12 direct and indirect jobs could be created EU-OEA (2010) per MW of marine energy installed.

Direct jobs are those within the marine energy sector (e.g. those building or operating marine energy devices or providing dedicated specialist service), whereas indirect jobs are jobs in supporting or secondary service industries which are strengthened by the growth in the marine energy sector (e.g. suppliers). A breakdown of the types of job created by marine energy is given in Figure 75.

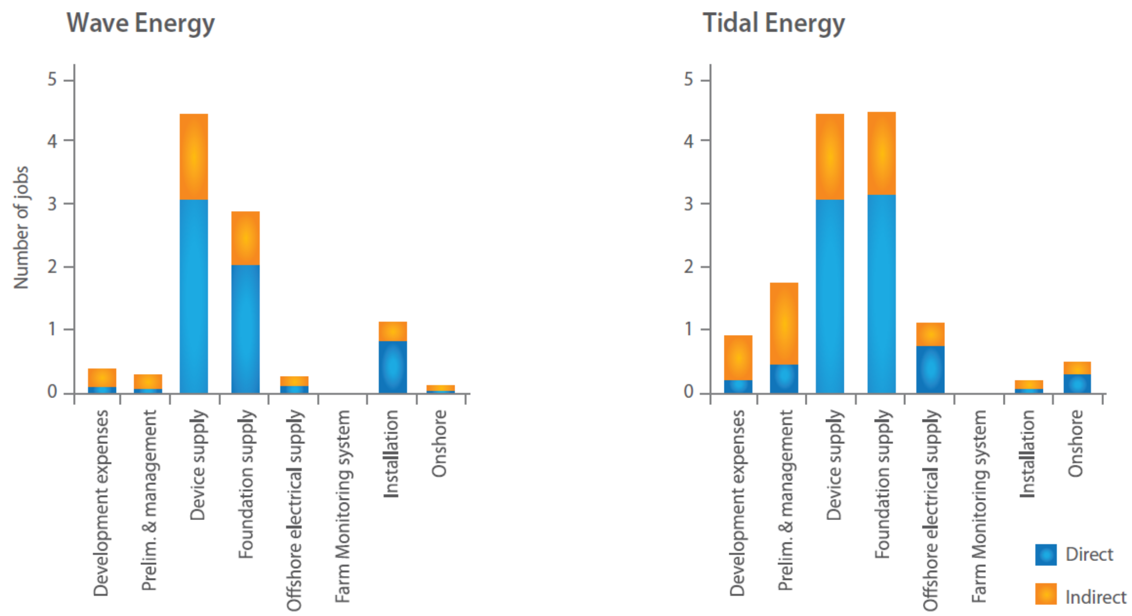


Figure 75: Job creation per MW of installed marine energy capacity (EU-OEA, 2010) in (E&A/UoE, 2012)

It can be seen that there are some differences between the job creation characteristics of wave and tidal power. There are also differences between the different devices within each industry because, for example, floating devices have different structures and installation or maintenance methods than do those devices which are fixed to the seabed. Nonetheless it is clear that the largest portion of job creation comes from supplying the devices and their foundations.

Both the number of jobs created and the investment required to install a MW of marine energy will decrease with time (they are of course linked). Indeed some device developers with an eye on cost reduction more than job creation have claimed that the EU-OEA estimates may be too high. Given the uncertainty around technology development and for example the definition of “indirect job”, it is difficult to make accurate predictions. Nonetheless, by basing an estimate on some further assumptions, it is easy to see that the benefits from Chile playing a more active role in marine energy development could be considerable (Table 18).

Table 18: Potential jobs and investment resulting from different growth scenarios

Strategy scenario	**Installed marine energy capacity (MW)**		**Total jobs (direct and indirect)**		**Investment (m USD)**	
	2020	**2030**	**2020**	**2030**	**2020**	**2030**
	Assumptions:		*Jobs/MW*		*m USD /MW*	
			9	*6*	*3*	*2*
Accelerated development	46	719	418	4,453	139	1,484
Development	26	471	235	2,906	78	969
Deployment	2	194	18	1,171	6	390

10 Recommendations

As outlined in the introduction, this project has sought to deliver a series of specific recommendations to best achieve the strategic policy objective (a “development strategy”) recently established by the Chilean government (see Chapter 3, page 12). Recommended actions and activities have been included throughout the main report and are presented in Table 19 in an overview format.

Table 19 Collated list of recommendations from this project

(Recommendations classified as urgent are presented in bold type)

Ref.	Activity	Possible action holder(s)	Timescale[47]	Page
Chapter 1 – Introduction				
Chapter 2 – Overview				
2-A	Integration of renewable energy policy with wider energy, economic and regional development policies; consider novel energy uses	Ministry of Energy / CER	Ongoing	8
2-B	Publication of annual industry status update	Ministry of Energy / CER	Ongoing	9
2-C	Definition of future role of wave and tidal energy in Chile	Ministry of Energy / CER	Ongoing	11
2-D	Characterisation of tidal resource	Ministry of Energy / CER	Short term	11
Chapter 3 – The Chilean Ministry of Energy´s Marine Energy Strategy				
Chapter 4 – Regulatory framework				
4-A	Development of the regulatory framework (implementation of proposed improvements)	Chilean Government	Short term	16
4-B	**Development of clear rules for marine energy concessions; reduction of uncertainty around transfer of powers from SUBSECMAR (Ministry of Defence) to the Ministry of National Assets**	**Chilean Government**	**Urgent**	**18**
4-C	Marine energy consents training for key staff	Chilean Government	Short term	18
4-D	Consultation to support the development of a leasing process	Chilean Government	Short term	19
4-E	Leasing of priority development zones for marine energy	Chilean Government	Medium term	20
4-F	Production of a licencing manual for marine energy projects	CER	Short term	22
4-G	Sharing of information gathered for licence approvals	Chilean Government	Short term	22
4-H	Risk-based environmental impact assessment	Ministry of Environment	Short term	23

[47] See definitions, page 5

4-I	Consideration of the wider impacts of marine renewable energy projects in EIAs	Ministry of Environment	Short term	24
4-J	Possible streamlining of the regulatory framework for marine energy projects	Chilean Government	Medium term	24
4-K	Voting rights for Ministry of Energy representatives on national and regional commissions for coastline use	CNUBC / CRUBC	Short term	25
4-L	Identification and designation of priority development zones for marine energy	Ministry of Energy / CNUBC / CRUBC	Short term	26
4-M	Strategic Environmental Assessment (SEA)	Ministries of Environment & Energy	Short term	27
4-N	Creation of a national marine atlas and marine plan for Chile	Chilean Government	Short to medium term	27
4-O	Creation of health and safety working group for the marine energy sector	Ministry of Labour and Social Security	Short term	28
4-P	**Development of a robust marine energy strategy; appointment of independent steering group to review, advise and publish progress**	**Ministry of Energy / Strategy Review Group**	**Urgent; ongoing**	**30**
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5-E	Market niches - wave-powered desalination and water pumping for the mining industry	Chilean Government / ICE	Short term	49
5-F	Market niches – wave-powered desalination for drinking water	Chilean Government / ICE	Short term	50
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5-H	**Implementation of pilot projects and coordination with the ICE.**	**Ministry of Energy**	**Urgent**	**56**

5-I	**Establish ICE to lead on strategic national research projects; create national plan for marine energy RD&I**	**InnovaCORFO**	**Urgent**	**57**
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Recommendation 10-A: Re-evaluation of recommendations as circumstances and understanding develop

The recommendations made here are based on research and consultation carried out in 2013, and it would be beneficial if they could be reviewed and updated on a regular basis, possibly by the proposed **independent strategy review group** (Recommendation 4-P, page 30) and the **Ministry of Energy**.

Ministry of Energy / Independent strategy review group **Ongoing**

11 Conclusions

The possibility of Chile producing significant amounts of renewable power from waves and tide has been gaining increasing national and international attention in recent years, fuelled by the levels of resource available in Chile, recent technological progress internationally and the vision, drive and commitment of certain organisations and individuals. The economic and regional development benefits of marine energy deployments are also increasingly widely recognised. Given the early development stage of wave and tidal power technologies, there are numerous challenges to be overcome before commercial projects can happen in Chile. Whilst this will take some time, there is a sense of urgency to define what the eventual contribution of marine energy to Chile´s energy mix might be, and what role Chile wishes to play in marine energy development in the interim.

This study has combined knowledge of the energy situation in Chile with experience and understanding from more than a decade of marine energy activity internationally and specifically from Orkney in the UK, where 20 wave and tidal devices have been deployed and 11 commercial leases awarded. A lot has been achieved in the UK, but many lessons have also been learned and there are mistakes to be avoided. This project has the collective insight to propose steps that can help maximise Chile´s marine energy potential.

This was a desk based study with extensive consultation and stakeholder engagement. This report has been organised so that it both gathers and disseminates information related to marine energy development. This project was developed in collaboration with the Ministry of Energy as an input to the ongoing development of marine energy strategy in Chile and has brought together over 200 different organisations and individuals through workshops and interviews held in nine of Chile´s fifteen regions, to define recommendations for the development of marine energy in Chile. The project has also drawn on knowledge and experience from international marine renewable energy developments in some 15 countries (see Project Methodology, section 1.4, page 3).

11.1 Chile´s energy situation

To deal with the competing pressures of rapidly increasing demand for energy and the imperative of reducing greenhouse gas emissions, energy use throughout the world is set to go through a revolution over the coming years. Chile is also faced with its own specific problems such as relatively high and volatile electricity prices and comparatively low energy security as a result of dependence on fossil fuel imports. The Chilean electricity market is deregulated and operates on a lowest cost model. Renewable energy incentives and targets do exist (and have recently been increased) however these are technology-neutral and not aimed at supporting pre-commercial technologies such as wave and tidal.

11.2 Chile´s marine energy resources

As has been shown in previous studies (E&A/UoE, 2012) (Garrad Hassan, 2009), Chile has a vast potential for generating power from waves and a much smaller but still significant tidal potential. Chile´s renewable energy resources dwarf the country´s current electricity demand, and wave and tidal are increasingly recognised alongside other forms of renewables as sustainable alternatives to coal, diesel and gas-fuelled generation for an independent national energy supply.

Wave energy is Chile´s largest renewable resource - 240GW according to a study by Baird & Associates - and wave activity is high enough for power production on all Pacific-facing coasts. It could be argued that Chile is the best place in the world for wave energy, with over 4,000km of coast exposed to consistent high energy swells, and with all of the country´s energy demand located at or relatively near this coast. Chile´s tidal energy resources are also significant but are perhaps one hundredth the size of the total wave resource. The largest tidal currents are found in the Magellan Strait (8-9 knot tides) and the Chacao channel near Puerto Montt (7 knot tides), but further smaller tidal streams can be found at perhaps 20 specific locations throughout the south of Chile. These resources have not been studied in detail and need to be better understood.

11.3 Current technology status and cost of energy

Wave and tidal power technologies are both at a pre-commercial stage of development and the cost of power from these sources is currently higher than Chilean electricity. Tidal power technology is more developed than wave and is believed to have lower generation costs at present. This can be understood partly by comparing working principles. All successful tidal power devices make electricity from rotary turbines in flow. In this sense they are similar to wind turbines, and tidal power has been helped by technology transfer from that industry. The challenge of wave energy is to generate power from the low-speed and high-force oscillations of waves, which is a more complex problem with apparently a more diverse range of power conversion solutions.

The fact that marine energy has yet to be commercialised means that Chile has a chance to play a development role and establish a manufacturing capacity which would be difficult to achieve in more established industries such as wind and solar, where equipment is largely imported. There are specific areas of marine energy technology development which have received little attention to date and where Chile could play a leading role – for example in desalination, water pumping or the development of smaller systems for isolated communities.

The balance between costs, revenue, business conditions and competitive alternatives will determine the commercial viability of a technology in a particular location. There are particular conditions in Chile that are worthy of note when considering this balance. Both the cost of energy from wave and tidal technologies and the commercial conditions may be quite different in Chile compared to for example the UK:

- Labour and manufacturing costs in Chile are lower; devices may be built cheaper;
- General vessel, crew and diver rates are lower in Chile than in many other areas;
- Free trade zones and tax incentives exist in the extreme north and south of Chile;
- Chilean tidal sites are more protected from waves and floating or suspended debris (ice/trees/silt) than other sites internationally e.g. the Pentland Firth (UK) or the Bay of Fundy (Canada). This will tend to reduce structural, installation and other costs;
- Installing and maintaining wave power devices could be more challenging than in the other areas due to near-constant wave action and steeply sloping seabeds, but increased production from the high energy wave climate will compensate for this to some extent.

Based on the comparative study of Chile and the UK carried out as part of this project, it is estimated that the cost of tidal energy may be as much as 16% lower in Chile than in the UK (due mainly to reduced labour and standard vessel costs), and as much as 30% lower for wave energy (due to these factors and increased power production). Globally it is believed that the levelised costs[48] of wave and tidal energy will fall as more devices are installed and innovation takes place. At the same time fossil fuel prices are likely to continue to rise, despite the recent influences of shale gas deposits on some gas prices. Another short term stabilising influence on the cost of electricity in the two main Chilean electricity grids is their planned interconnection in 2018. However, in the medium and longer term it is likely that an upwards price trend will continue, and certain that pressure to reduce carbon emissions will also increase.

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[48] Levelised cost considers the capital, operational, maintenance and decommissioning costs of a project offset against energy production over the lifetime of a project.

On current trends, marine energy may be able to compete with other forms of renewables in the main electricity grid by the mid-2020s. Applications of marine energy where existing costs are higher (such as replacing diesel generation) or where power is used directly (such as seawater pumping) may be viable earlier. Tidal power may already be competitive with diesel generation in some cases, particularly in remote areas.

11.4 Marine energy strategy for Chile

"The Chilean Government recognises the importance of developing renewable energy sources from Chile´s extensive marine resource in order to improve security of supply and mitigate climate change effects whilst contributing to the economic and industrial development of the nation.

To guarantee the maximum economic benefits associated with the use of the country´s marine energy resources, the Chilean Government wishes to establish a "Development Strategy for Marine Renewable Energy" which will allow the country to support the growth of the sector and take an active role in the development of marine energy in Chile´s territorial waters"

Chilean Ministry of Energy draft Marine Energy Strategy vision statement (2013)

The Chilean Government has published a National Energy Strategy for the period 2012-2030. The main pillars of this strategy are to increase the contribution from non-conventional renewables and to increase energy efficiency. The Ministry of Energy is now developing a Marine Energy Strategy (see vision statement above) which it plans to publish in 2014.

The fact that the Ministry of Energy aims to establish a development strategy for marine energy is an extremely supportive development, as is the fact that the Ministry of Energy plans to encourage cross-ministerial coordination on marine energy - there are many policy areas where coordinated action from different government ministries will be required to successfully support the marine energy industry. The announcement of a total 27m USD of funding to create a marine energy centre of excellence and to support the first wave and tidal pilot projects is a very positive development, as are the various related studies and regulatory changes which have been implemented or proposed.

The Ministry of Energy however, must necessarily define activities in its strategy which are within that organisation´s remit to carry out. This can include identifying barriers to marine energy development and setting up working groups with other ministries to try and combat these (for example with the Ministry of Defence and Ministry of National Assets on maritime concessions), but change required in these areas of government must be implemented by the ministry responsible. Similarly, there are benefits of marine energy in terms of job creation and investment which are central to the case for marine energy, but on paper at least, they are the concern of the Ministry of Economy rather than the Ministry of Energy.

It may be that the formation of an independent group with responsibility for tracking progress on marine energy development and updating strategic recommendations would be beneficial. Such a group could be made up of experts and representatives from different governmental and non-governmental agencies (including industry and academia), similar to the Marine Energy Group in Scotland. If assembled by central government and backed by the right organisations, such a body could be empowered to make independent recommendations and influence policy in a way that could be more difficult to achieve from within government.

Whilst the Chilean Government sets and enforces targets for overall renewable energy supply, it generally refrains from setting specific targets for individual types of renewables such as wave or tidal. The identification of achievable targets can help drive the sector forwards, and an independent marine energy strategy group could be well placed to propose such targets (even if they were aspirational) as part of their recommendations.

Case study 11-A: Marine energy development in the UK

The UK and in particular Scotland, has taken a position of global leadership in marine energy development. This case study examines the success factors in Scotland, and what lessons can be learned from a Chilean perspective.

The last decade has seen a steady growth in the number of wave and tidal technologies installed in Scottish waters – and in the last two years the numbers have increased exponentially. At the European Marine Energy Centre in Orkney, all 14 wave and tidal energy test berths are contracted (EMEC, 2013). Around Scotland's coast, Agreements for Lease for more than 1.7GW of wave and tidal energy projects have been awarded to marine energy technology companies, their utility and industrial partners and project developers.

The reasons behind the rapid acceleration of the marine energy sector in Scotland are twofold; firstly, Scotland has an excellent geographical position on the edge of the Atlantic Ocean – with 10 per cent of Europe's wave and 25 per cent of its tidal resource. Secondly, and of equal importance – a decade ago the Scottish Government made a very clear commitment to develop a marine energy industry in Scotland. Since then, the Government has worked closely with industry to put in place the crucial policy measures to enable this new industry to become established and grow.

Scotland has a long history in marine energy. In the early 1970's (at a time of high oil prices following the OPEC price shock) Professor Stephen Salter of Edinburgh University made a prototype wave energy device known as the Salter Duck. The discovery of oil in the North Sea, however, put a halt to the UK's marine energy research programme until it was resurrected decades later with the installation of the 500kW Limpet device on the island of Islay in 2000.

However, the significant growth of Scotland's marine energy sector over the past decade can be directly attributed to the establishment of EMEC in Orkney in 2003, and the publication of the Scottish Government's Marine Energy Group Road Map in 2004 (FREDS/MEG, 2009). The Marine Energy Group brought together government, academia and industry to understand the challenges and opportunities of marine energy and to present clear recommendations on what measures should be put in place. These recommendations were taken on board and formed the foundation for the industry we now see emerging today.

The work undertaken by technology developers at EMEC has enabled Scotland to prove that marine energy technology works, whilst the Marine Energy Group Road Map and other road mapping exercises have helped to put in place the policies and processes to enable the development of a marine energy market.

The crucial lesson for the development of a marine energy industry is that all policy measures must be developed in parallel: A partial or uncoordinated set of policy measures is unlikely to provide the political and industrial drivers required to progress the development of a successful marine energy industry.

For instance, a well-structured consenting and licencing system will not secure the development of a marine energy industry where there is no ready access to grid infrastructure. Or alternatively, access to grid will not bring success if there is not a sufficient tariff to attract investment (see Recommendation 4-P, page 30).

11.5 Regulatory framework

11.5.1 Maritime concessions

It would be beneficial to clarify the rules for obtaining maritime concessions for marine energy projects and the impact of the proposed transfer of responsibility for these from SUBSECMAR (Ministry of Defence) to the Ministry of National Assets. The discussion around that legislative change presents an opportunity for marine energy related issues to be considered, and for a mechanism to be established which prevents speculative concession applications or resource hoarding. This has been a problem, to some extent, in the wind and solar sectors in Chile and also in the early commercial marine energy leasing rounds in Scotland/UK. A recent study carried out by Philippi Abogados considered marine energy developments of around 100MW size and concluded that the process of securing a maritime concession for such projects (in which multiple authorities are involved) was "slow, complex and uncertain" and could take at least one to two years to complete at best.

Nonetheless, some Chilean device developers have successfully deployed part-scale prototypes using the short-term concessions available for research or measurement purposes. Further consideration is required for the projects of less than 100MW size that will be installed in the short to medium term.

11.5.2 Permits and licences

There is a lack of technical experience around permitting wave and tidal device deployments in Chile which has the potential to delay projects and be a barrier to the development of appropriate marine energy regulations. Experience elsewhere in the world has shown that regulatory agencies can be ultra/excessively cautious when undertaking such work. A risk-based approach taking into account international deployment experience is essential for evaluating early device deployments; otherwise projects can be delayed unnecessarily and incur excessive costs securing the permissions required (planning consent, environmental impact assessment (EIAs), navigational permits, electrical concessions, etc.). The Ministry of Energy´s strategy includes proposals to clarify this situation. In addition to the EIA guide being produced by the Ministry of Environment, it would be helpful to produce a manual for project developers which outlines the concession, permitting and licencing steps required to realise marine energy projects in Chile[49]. This project could also consider the potential for streamlining to minimise the number of licences required and regulators involved, and to enable coordinated consultation to reduce licence determination timescales.

11.5.3 Marine planning

A national strategic environmental impact assessment should be considered in order to identify areas of the country with lowest environmental risk for marine energy projects. Combining this with the results of the planned infrastructure study and an evaluation of where marine energy projects can be implemented at lowest cost would enable priority development zones for wave and tidal energy to be identified in partnership with the regional and national commissions for coastline usage (CRUBC/CNUBC). It would also be beneficial to grant voting rights for the Ministry of Energy representatives on these commissions, who currently have observer status only (E&A/UoE, 2012).

11.5.4 General

Setting up a health and safety working group tasked with creating a suitable risk management and control framework for Chile´s marine energy sector would be of benefit to the sector.

It is important to learn from rather than copy existing regulatory provisions (either internationally or nationally from other sectors). Chile has a chance to set new and appropriate standards for marine energy that could become a model for other countries if the right balance is struck between control and facilitation. Renewable energy can provide an excellent opportunity for community engagement and even leadership with regards to project development and site selection.

[49] Scotland has produced a Draft Marine Renewables Licencing Manual for this purpose, see: http://www.scotland.gov.uk/Resource/0040/00405806.pdf

11.6 Research, Development and Innovation (RD&I)

The Ministry of Energy and CORFO aim to consolidate Chilean research capacities and encourage the development of specialised devices and human capital through applied RD&I. The planned creation of an **ICE** for marine energy is a key part of this, as are the various international partnerships which the Ministry of Energy has agreed.

CONICYT and Chilean Universities may wish to consider coordinating Chilean research effort with the international marine energy industry through links with international energy research organisation (such as the EERA[50]) a project similar to the UKERC marine energy research atlas (UKERC, 2012). CORFO could consider a similar initiative for applied RD&I.

Technology cost reduction and adaptation is a priority and may be best focused on areas which require Chile-specific solutions. For example:

- Long wavelengths will influence the geometry of wave energy devices;
- High wave consistency requires new/more resilient installation methods;
- Wave energy development on steep seabed slopes requires new mooring designs;
- Seismic and tsunami risk must be considered;
- Synergies between tidal energy and run-of-river technologies could be usefully explored

Support for the development and adaptation of foreign devices to Chilean conditions can be considered alongside the growth of new Chilean technologies. The goods and services that can be produced or provided in Chile could be identified and development in these areas encouraged.

The first steps towards understanding Chile´s marine energy resources have been taken, but Chile´s tidal resources still need to be better understood. Mapping seabed bathymetry at high resolution in key resource areas and establishing the patterns of wave energy distribution near the coastline (<10km) would be beneficial. National assessments to date have considered only total marine energy resources, so further work to identify which sites are most economically viable is now needed and could be used to support the identification of priority development zones.

It would be beneficial to prioritise environmental research based on experience to date/local sensitivities/risk/uncertainty. Baseline studies are required but ideally will focus upon features where there are likely and quantifiable effects. Of equal importance are the dissemination of information about marine energy and the benefits of such projects, to avoid conflicts due to lack of information.

There are a number of niche markets within marine energy which have received comparatively little attention to date where Chile could take a leading role, including:

- Using wave energy to desalinate or pump seawater. The Chilean Government estimates that by 2020 the copper mining industry alone will require 6.3TWh of energy for this.
- Developing small-scale marine energy systems for the thousands of isolated communities, salmon farms and tourist sites in Chile with limited or costly access to energy and/or water.

It would be beneficial to link the activities of the planned ICE and Wave and Tidal Pilot Projects and to coordinate these projects with the work of other marine energy centres internationally, to transfer lessons learned and avoid duplicating efforts. The extent to which these initiatives may be able to

[50] European Energy Research Alliance, see http://www.eera-set.eu/

support future device deployments, for example by pre-permitting sites or providing access to shared infrastructure or test facilities, is also worth exploring (see Recommendation 5-H, page 56).

11.7 Infrastructure and supply chain

11.7.1 Electricity grid and routes to market

Chile is currently relatively well served by coastal electricity grid capacity, with around 50 possible connection points along its coastline. The grid is however comprised of 4 separate systems, the distance between connection points may be hundreds of kilometres and many of the more remote communities along the coast in Chile are not yet grid connected. The Ministry of Energy has confirmed that it plans to consider the electrical grid capacity requirements for marine energy, but no specific initiatives have been announced as yet.

Marine energy projects in the UK and elsewhere have been delayed by inadequate access to the electricity grid and the established commercial arrangements for grid connection and the use of systems charging regimes have also proven to be barriers to investment leading to project delay and cancelation. It is therefore helpful to be aware of these problems and consider how they might best be avoided. One solution can be exploiting markets which do not need grid connection for energy use i.e. off-grid communities but also energy applications such as desalination, water pumping and direct/dedicated industrial use (including if necessary dedicated electrical cable connections).

11.7.2 Infrastructure and supply chain

The Ministry of Energy plans to commission an infrastructure and services study for marine energy. The results of this study could be used to promote appropriate supply chain capacity building, the designation of priority development zones and the focusing of RD&I programs and other marine energy policies. It would beneficial if the next port works plan by the Port Works Agency (Ministry of Public Works) could consider marine energy. It is important to consider the supply chain requirements for short term technology development (RD&I) alongside longer term and broader project development requirements which include survey, planning, manufacturing, installation and maintenance services, etc.

Links with international institutions already active in marine energy training could be strengthened to support capacity building in Chile. Chile Valora, the Ministry of Education and the Ministry of Labour may wish to consider marine (or more generally, renewable) energy training in their programs.

Trade associations can be influential in promoting industry development and those based in Santiago may wish to consider expanding their activities to those regions with greatest marine energy potential.

11.8 Finance

Given the early stage of sector development, financing projects can be difficult. Increased risk awareness and tighter credit controls have made it more difficult to raise finance in recent years. Relatively minor government support can however be used to leverage significant private sector investment.

Chile´s renewable energy (NCRE) incentives are not aimed at pre-commercial technologies but do influence prices for renewables in the marketplace. Other existing funds and RD&I incentives have been sufficient to support some Chilean companies to test part-scale prototypes and for various university projects and other studies. The planned 27m USD of funds for pilot projects and an ICE should guarantee the first large at-sea marine energy deployments in Chile as well as a continued level of applied RD&I activity.

Several countries continue to offer generous subsidies for generation that are unlikely to be replicated in Chile. Rather than seeking to compete with the support available internationally for MW-scale grid connected farms, Chile may wish to consider supporting projects in niche markets.

For a development strategy to be realised, sufficient support for pre-commercial projects is required to allow Chile to take an active role in marine energy development, rather than waiting to deploy technologies developed abroad. As shown in Figure 8, with the financial support mechanisms currently available there is the potential for a gap in activity between the end of the funded phase of the pilot projects and the onset of commercially viable projects. A broader base of support may need to be established. It may be possible for Chile to pursue a development strategy without subsidising large scale pre-commercial deployments, in particular by:

- Supporting RD&I projects which reduce technology risk and bring down costs – these can be coordinated with the global marine energy industry but could also support Chilean technology developers.
- Creating new studies and funding instruments to support the development of niche markets within marine energy where Chile has natural advantages or a significant home market, for example in wave-powered desalination and water pumping or in developing systems for isolated communities.
- Maintaining some activity in the more conventional area of MW-scale grid connected prototypes, through the development of a new funding instrument to support for example an expansion of the planned wave and tidal pilot projects to include multiple devices (say 10 to 30MW capacity) in the medium term e.g. around 2020.

11.9 Regional analysis

Chile is a vast country with over 4,000km of coastline. Some of Chile´s fifteen regions are of comparable size to mainland Scotland, and marine energy policy must take this exceptional geography into account.

11.9.1 Norte Grande / Norte Chico

In the north of Chile, water and energy demand could drive the development of (possibly combined) wave power, desalination and seawater pumping plants. Demand in all of these areas is expected to rise due to continued growth in mining activity. High energy and water costs combined with tax benefits and a more benign operating environment could make wave energy projects viable earlier here than in the south. Fossil fuels make up 99% of the energy mix, so there is a pressing need to increase the contribution from non-conventional renewable energy in the grid. It is also understood for example that close to half of the isolated communities in Antofagasta region rely upon water tankers – the potential for community scale wave-powered desalinaton is very interesting and has received little attention to date.

11.9.2 Centro / Centro Sur

The central zone of Chile is likely to play a key role in the development of the country´s marine energy supply chain – device structures and components could be manufactured here. Collaborative planning between the private and public sector is required to promote the development of local industry. Given the high population density and intensity of coastal use in this zone, perhaps the most urgent challenge is to identify and reserve areas with potential for wave energy. Population density towards the south is lower but wave energy levels are higher, more seabed of suitable depth is available and as projects can still connect to the central Chilean electricity network (*Sistema Interconectada Central*, SIC) the potential for commercial wave energy farms in the long term is greater.

11.9.3 Los Lagos

Los Lagos is a strategically important region of Chile as it possesses both wave and tidal resources in abundance. This region is a transition zone between the most populous areas of Chile and the Patagonia south. There are many isolated communities scattered among islands, fiords and channels. Energy costs (usually from diesel generation) are high, so there is interesting potential for renewables, including wave and tidal. The Chacao channel is the second most important tidal stream in Chile after the Magellan Strait, and projects here would be able to connect to the SIC. Effort will be however required to design a project which is environmentally and socially acceptable in this sensitive area; a coastal but onshore wind project in Chiloé was recently blocked due to perceived risk of impacts on blue whales and archaeological heritage.

11.9.4 Aysén, Magallanes and offshore islands

The marine energy potential of Aysén has historically been overlooked but interesting tidal streams do exist in close proximity to isolated communities, salmon farms or tourist sites. Magallanes is home to Chile´s largest tidal resource in the Magellan strait, but there are many smaller sites with good potential, such as the Beagle and Fitzroy channels. The tidal resources of such sites need to be better understood (as does the run-of-river potential). Although wave energy levels on the Pacific coast are extremely high in Aysén and Magallanes, these are relatively inaccessible and unlikely to be developed for the foreseeable future. Smaller wave power projects in lower energy sites such as the north of Aysén or wider parts of the Magellan Strait may however be possible. The marine energy potential of Chile´s offshore islands and in particular Easter Island and Juan Fernandez would also be interesting to explore.

Chile´s Regional Governments and the Subsecretary of Regional Development may wish to consider the potential for drinking water and energy supply from marine renewables as part of their strategies for remote communities. It would be beneficial to identify the most promising sites in coordination with the regional coastline use commissions (CRUBC).

There is interesting marine energy potential in all of Chile fifteen regions (see Table 17: Suggested regional priorities for marine energy development, page 130).

11.10 Future growth of marine energy in Chile

The cost of marine energy will fall as more devices are installed around the world, and as innovation takes place. The point at which projects become commercially viable in Chile will depend to a large extent on cost reduction efforts taking place outside of Chile, and on future energy costs which are uncertain. It is not possible to say how future developments will take place but it is clear that government support at the pre-commercial stage can increase installation activity and hasten the onset of commercial projects.

As tidal power technologies are closer to commercialisation it is probable that more tidal than wave power capacity will be installed at first. There are however a limited number of tidal sites and once commercialised, wave power will be able to continue to grow more rapidly (see Figure 72, page 136).

In the evaluations made, current Chilean marine energy policy constitutes a **deployment plus strategy** scenario where regulatory changes are made and an increase in RD&I activity has been supported, but device installations may be limited until the advent of commercial projects, probably around the mid-2020s. If further support pre-commercial support can be made available, for example to support market niche projects in the short term and perhaps a 10-30MW expansion of the pilot projects in the medium term, this could constitute a **development strategy scenario** sufficient for Chile to reap the additional economic benefits (i.e. jobs and investment) associated with an active role in marine energy development. In the most optimistic scenario, support for multiple pre-commercial farms would guarantee a leading role for Chile through an **accelerated development strategy** (see graphs in Possible growth scenarios, Chapter 9, page 132).

Chile has a tremendous opportunity to capitalise on the global growth in ocean energy technologies and to take part in the common efforts of governments, international agencies and private developers to encourage the development of a worldwide marine energy market. It is hoped that this report will support this work, and act as a template for the ongoing development of marine energy strategy in Chile.

Recommendation 11-A: Review of conclusions as circumstances and understanding develop

It would be beneficial to review the conclusions made in this report on a regular basis, possibly by the **Ministry of Energy** and the proposed **independent strategy review group** (Recommendation 4-P, page 30).

Ministry of Energy / Independent strategy review group **Ongoing**

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Key to maps (see Chapter 8, page 96 onwards)

Wind farms (2013)
Granjas eólicas

- Operational / *En operacíon*
- Approved / *Aprobado*
- Qualification Stage / *En calificación*

Solar farms (2013)
Granjas solares

- Approved / *Aprobado*
- Qualification Stage / *En calificación*

Protected areas / *Áreas protegidas*

Benthic protection areas / *Áreas de protección bentónicas*

Desalination Plants / *Plantas desalinizadoras*

Salmon farms / *Granjas de salmón*

Fishing coves / *Caletas pesqueras*

Ports with shipyard / *Puertos con astillero*

Ports / *Puertos*

Mines / *Minas*

Oil/Gas Rigs / *Plataformas petrolíferas/gas*

Refineries / *Refinerías*

LNG terminals / *Terminales GNL*

Power stations
Centrales eléctricas

- Thermoelectric / *Termoeléctricas*
- Hydroelectric / *Hidroeléctricas*
- Substations / *Subestaciones*

Power lines
Líneas de transmisión eléctrica

- 33KV
- 44KV
- 66KV
- 100KV
- 110KV
- 154KV
- 220KV
- 500KV

Bathymetry
Batimetría

- -100m
- -1000m

Wave power
Potencia undimotriz
[kW/m]*

- 115 -120
- 105 -110 (Magallanes)
- 95 - 100
- 85 - 90
- 75 - 80 (Aysén)
- 65 - 70 (Los Lagos)
- 55 - 60
- 45 - 50 (Centro Sur)
- 35 - 40 (Centro)
- 25 - 30 (Norte Chico)
- 15 - 20 (Norte Grande)
- 5 - 10

Potential tidal energy sites
Sitios potenciales para energía mareomotriz

Location/*Localización*	**Peak flow**/*Flujo maximo* (m/s) Ebb tide *Marea vaciante*	Flood tide *Marea creciente*	**Estimated mean kinetic power (MW)** *Potencia cinética media estimada*
1. Robinson Crusoe	1.54	2.06	11.9
2. Isla Santa María	1.28	1.54	14.0
3. Canal de Chacao	4.63	2.57	800
4. Canal Calbuco	1.29	2.06	7.9
5. Estero Reloncaví	0.77	2.31	64.8
6. Canal Dalcahue	2.57	2.06	10.1
7. Bahía Quellón	0.51	2.06	2.7
8. Canal Chaiguao	0.51	2.06	5.0
9. Golfo Corcovado	0.51	2.06	31.1
10. Canal Carbunco	2.06	0.51	1.9
11. Canal Jacaf	0.51	2.57	89.2
12. Estero Elefantes	1.80	3.08	73.5
13. Angostura Inglesa	3.08	1.54	7.8
14. Angostura Kirke	4.63	6.17	33.2
15. Mal Paso	7.20	5.65	44.1
16. Canal Fitz Roy	2.16	1.54	6.3
17. Puerto Curtze	1.64	1.03	3.5
18. Isla Magdalena	1.03	2.06	14.7
19. Bahía Gente Grande	1.03	1.54	19.2
20. Segunda Angostura	2.06	2.57	734.7
21. Puerto Sara	2.06	2.57	514.5
22. Banco Tritón	1.03	2.06	7.1
23. Primera Angostura	2.57	4.11	1,727.2
24. Cabo Posesión	1.03	2.57	274.9
25. Punta Dungeness	1.03	2.06	31.1
26. Canal Beagle	1.03	1.54	42.8

*5kW/m is considered the minimum wave energy level feasible for generation www.aquatera.co.uk

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