INTEGRATED OCEAN ENERGY MARKETPLACE TECHNICAL FEASIBILITY STUDY

ABERDEEN

Xodus House
50 Huntly Street. Aberdeen
AB10 1RS, UK

T +44 1224 628300
E gerardo.arteaga@xodus.academy
andrew.taylor@xodus.com

https://www.xodusgroup.com/this-is-what-we-do/x-academy/

Contents

1 EXECUTIVE SUMMARY 4

2 INTRODUCTION 14

3 PROJECT PARTNERS 17
3.1 The Australian Ocean Energy Group 17
3.2 Discovery Bay 17
3.3 Xodus and X-Academy 19
3.4 Additional Partners 20
3.4.1 Marine Energy Research Australia (MERA) 20
3.4.2 Onetide 20
3.4.2 OceanPixel 20

4 DEFINING THE MARKETPLACE 21
4.1 Marketplace Objectives 21

5 AUSTRALIA'S ENERGY CONTEXT 23
5.1 Existing Energy Network 24
5.2 Energy Supply 27
5.3 Significance of the Marketplace to Australia's Energy Transition (Blue Economy Markets) 29

6 POWER STRATEGY 33
6.1 Methodology Overview 33
6.2 Technology Review 33
6.2.1 Technology Readiness Level Concepts 34
6.2.2 Technology Review – Renewable Energy Generation 35
6.2.3 Technology Review – Energy Storage 35
6.3 Renewable Resource Assessment 38
6.3.1 Solar Resource 38
6.3.2 Wind Resource 41
6.3.3 Wave Resource 44
6.3.4 Tidal Stream Resource 48
6.3.5 Comparison of Renewable Resources 49
6.3.6 Assessment of Renewable Supply Opportunity 52
6.4 Electricity Demand Scenarios 53
6.4.1 Overview 53
6.4.2 Scenario 1 – Early Deployment 55
6.4.3 Scenario 2 – Base Case Deployment 57
6.4.4 Scenario 3 – The Wider Region 59
6.4.5 Scenario 4 – Discovery Bay Expansion 61
6.4.6 Scenario 5 – All In 63

6.4.7 Comparison of Scenarios 65

6.5 Energy System Modelling 67

6.5.1 Input Data 68

6.5.2 Energy System Model Outputs 77

6.5.3 Energy System Optimisation 80

6.6 Energy System Modelling Results 81

6.6.1 Overview of Findings 81

6.6.2 Scenario 1 – Early Deployment 82

6.6.3 Scenario 2 – Base Case Deployment 85

6.6.4 Scenario 3 – The Wider Region 87

6.6.5 Scenario 4 – Discovery Bay Expansion 90

6.6.6 Scenario 5 - All In 92

7 MARKETPLACE PRE-FEASIBILITY STUDY OUTCOMES 95

7.1 Summary of Recommendations: 96

APPENDIX A SCENARIOS 1 TO 5 – ENERGY SYSTEM MODELLING RESULTS 97

APPENDIX B POTENTIAL REVENUE ASSESSMENT 102

B.1 Methodology and Revenue Themes 102

B.1.1 Revenue Considerations 102

B.2 Business Plan Overview 105

B.3 Marketplace Roadmap: Demand Profile Utilised and Power Strategy 105

B.4 Economic Model 108

B.4.1 Overview 108

B.4.2 Model Assumptions 108

B.4.3 Cost Profiles 110

B.4.4 Marketplace Proposed Revenue 112

B.5 Cashflow Analysis 116

B.5.1 Overview 116

B.5.2 8.4.2 Cashflow Risk Considerations 117

B.5.3 Funding Considerations 119

B.6 Marketing 119

B.7 Marketplace Governance 119

APPENDIX C REFERENCES 121

1 EXECUTIVE SUMMARY

Marketplace Opportunity in Australia's Energy Context

Australia is undertaking a significant change in how electricity is supplied, distributed, and decarbonised. As over 85% of Australia's population resides 50 kilometres from the coast, ocean energy is widely accessible to demand centres. The change to electricity networks across Australia will see them re-designed to accommodate greater renewable energy as coal electricity generation and broader fossil fuels are removed from the energy mix. Standalone and local electricity supply will be desirable for small regional demand centres, rather than receiving electricity from a centralised generation system. These reforms will have greater consequences for regional communities with smaller demand centres that are located off-grid or on the fringe of grid.

Global energy and economy experts recognise there is an opportunity for ocean energy to significantly aid the energy transition and energy security of fringe and off-grid coastal communities. Australia has excellent ocean energy resources and a population that is clustered along the vast coastline, and the Australian Ocean Energy Group (AOEG) is an industry led cluster positioned to advance developments to harness this potential.

Off-grid demand centres are likely to already utilise some forms of renewable resources such as solar and wind energy, but also require gas or diesel power generation to build greater system resilience. Communities that rely on this type of energy security will eventually need to seek alternatives to fossil fuel power generation to support their economic growth. In Australia's coastal communities, as well as offshore electricity projects, ocean energy could provide the system resilience required to assist replacing fossil fuel generation.

Western Australia's southwest region is just one example of this. As illustrated in Figure 1-1, not all population concentrations overlay existing grid or generation infrastructure, and the electricity security challenges that AOEG's Integrated Ocean Energy Marketplace ("Marketplace") is planning to address is ubiquitous across Australia's coastal population. The validation of technical renewable resources, including ocean energy during this study is an important step towards providing visibility to meet AOEG's objectives, and in turn provide an example to similar coastal demand centres, to the benefits for adoption of ocean energy systems.

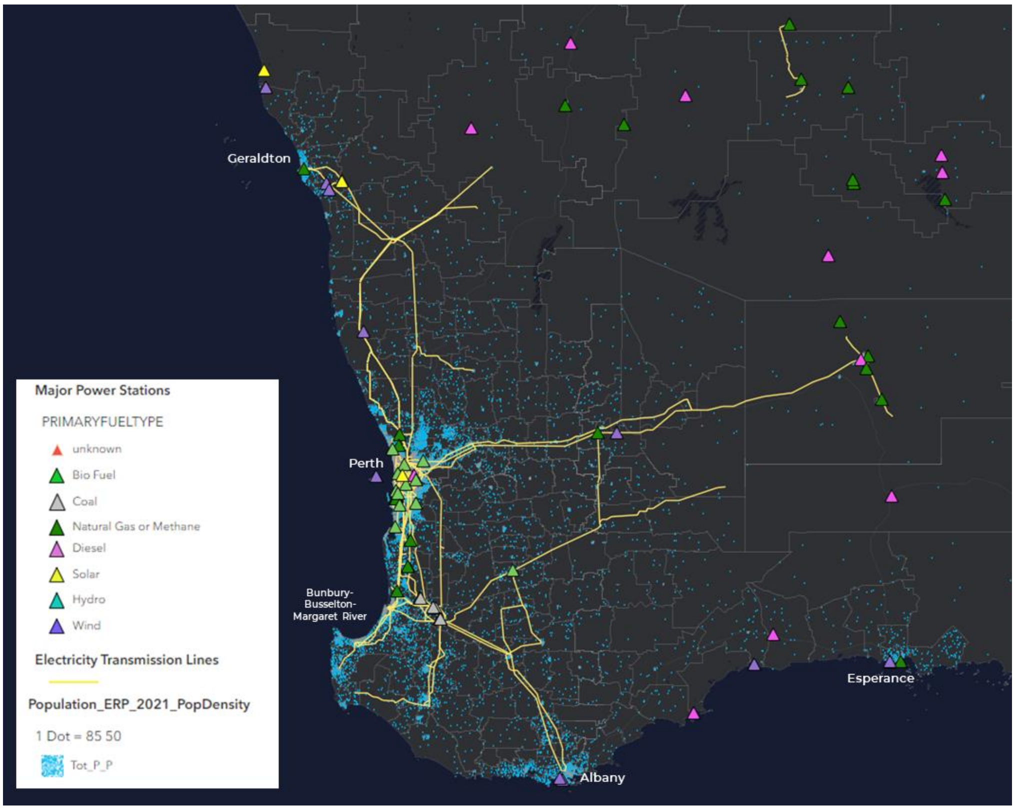


Figure 1-1. South-Western Australian population density, electricity grid access and power generation.

Xodus, AOEG and the University of Western Australia's Marine Energy Research Australia (MERA) have collaborated to deliver the Integrated Ocean Energy Marketplace Technical Feasibility Study through Xodus' energy transition skills initiative, X-Academy.

This technical feasibility study provides the results of an energy system modelling effort to identify a suitable integrated ocean energy system upon which the Marketplace will operate in a protected marine environment. Electricity produced from the integrated system will supply supplemental electricity for Albany's Historic Whaling Station as well as for AOEG's demonstration operations. With a focus on development of the system design, this report does not include analysis of the business and operation of the Marketplace but does identify key issues that will need to be addressed in the business and operational plan.

The future business plan for the Marketplace will use the technical assessment described in the body of this report as a foundation to assess the economic viability of the project. Economic viability will assess a selected demand scenario, the associated costs to develop and maintain the project, commercial opportunities based on AOEG's Marketplace business drivers and lastly, project funding considerations.

The Marketplace is proposed to be located at the site of Albany's Historic Whaling Station, within the Discovery Bay Tourism Precinct (Discovery Bay). Discovery Bay is situated near the coastal city of Albany, in Western Australia, in close proximity to world class wave resource for full-scale devices in the Southern Ocean. Discovery Bay, as a key tourism facility in the region, is also the foundation customer for energy supplied by the Marketplace and is uniquely placed to make demonstration of ocean energy a regional attraction. While not a highly dynamic wave resource, this location coincides with designated trial development area for MERA's reduced scale M4 wave energy device in Albany's outer harbour, King George Sound. In this protected environment, there is enough wave energy for a demonstration facility, however its commercial applications in this location are limited.

The key objective of AOEG's Marketplace is to showcase a working system to demonstrate how an integrated ocean energy system can serve as an alternative to diesel-supplied energy sources. The intent of the Marketplace is three-fold. First, it will provide a highly visible commercial supply of ocean energy to a keystone customer with a broad reach to public, private and market-based customers. Second, as an innovation hub; providing tangible demonstration of a system-based ocean energy microgrid in a highly relevant context. Third, it will serve as a catalyst for development of commercial ocean energy projects in other, more dynamic coastal environments.

MERA's M4 project will begin to test the regional supply chain capabilities and permitting framework for ocean energy developments in the region, which will feed into the Marketplace engineering requirements.

By creating a market-facing, systematic approach through the Marketplace, this can provide tangible and accessible demonstration of ocean energy supply, encourage more commercial ventures to explore and understand ocean energy and accelerate its adoption in combination with other renewable energies. Meeting the needs of the Marketplace's foundation customer, Discovery Bay, using an integrated and complimentary system of ocean energy, will be a crucial first step which will significantly improve the stability and dependability of its energy requirements, while providing a first of its kind market demonstration.

Validation of the system design for the Marketplace, through a detailed technical feasibility study, will provide AOEG with the confidence to proceed to the next stages of project maturation, including detailed design of the electricity generation facilities analysis of the business offerings and its associated economics, operating strategies and other key issues leading to development of a front end design and construction budget.

Renewable Resource Assessment

A resource assessment was undertaken using publicly available data to determine the renewable potential at the proposed site of the Marketplace – see Figure 3-1. This assessed wind, solar, wave and tidal resources; characterised temporal variability of resources; and established the complementarity of different sources to balance supply with demand.

Results from this assessment demonstrate that there are sufficient renewable resources in the Albany region, with wind demonstrating the most reliable resource, although also with strong availability of wave and solar. The tidal energy resource was identified as relatively un-energetic and was not considered a viable energy option. By observing these identified resources in monthly time series, seasonal variability across wind, solar and wave energy appears complementary at the proposed Marketplace site. It is recommended that AOEG should conduct a definitive resource assessment to obtain a complete and granular dataset to increase the confidence of the identified resource potential.

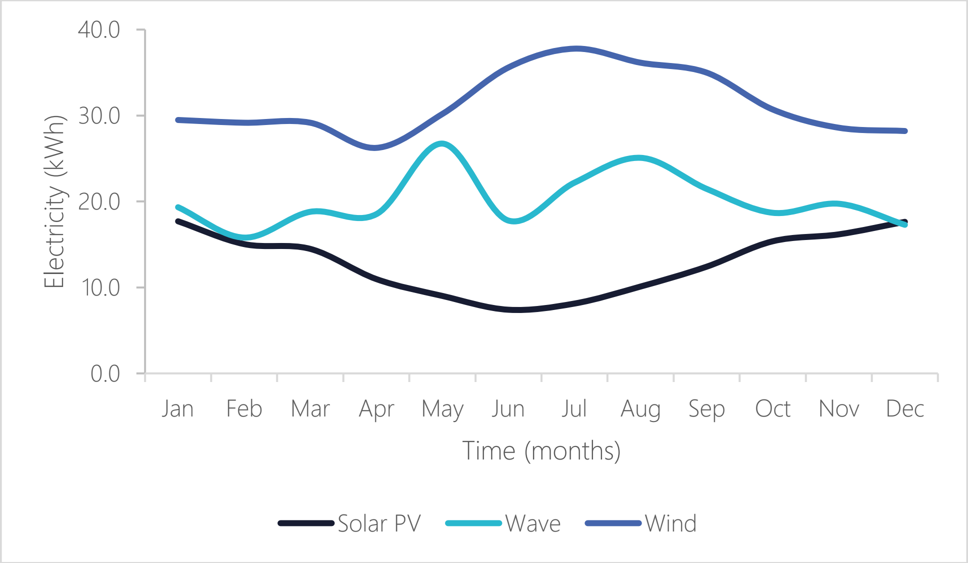


Figure 1-2. Seasonal variability of renewable resource at project site.

Electricity Demand and Supply Modelling

Five demand scenarios were created to identify different possible business outcomes for the Marketplace and the magnitude of impact on adjacent community needs. Scenario phase 2 aligned with the core objectives and needs of AOEG and Discovery Bay, they were selected as the preferred Minimum Viable Product (MVP) scenario to progress as the demand base case for the Marketplace, Figure 1-3 illustrates the typical daily demand profile for scenario phase 2.

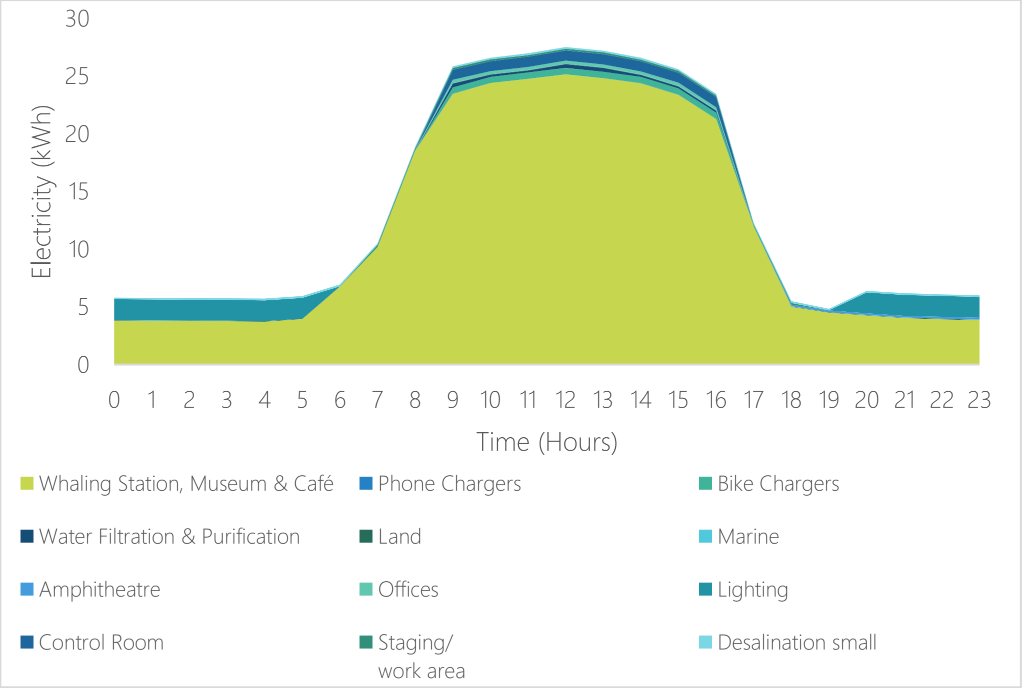


Figure 1-3 Scenario Phase 2 – Hourly electricity demand profile

The quantified electricity demand for scenario phase 2 was tested against the identified renewable resources to determine if demand could be balanced with the available renewable energy supply, as well as the required capacity size for solar, wind and wave resources. Battery storage was also integrated to strengthen system resilience. This improved the understanding of how system design will have to change as electricity demand increases and becomes more complex.

Energy system modelling identified three options for installed solar, wind and wave capacity to meet the scenario phase 2 demand profile. The three options observe a difference in energy system performance when the cost to resilience trade-off is considered. Option Phase 2b comprised an intermediate cost-resilience balance, as detailed in Table . This was determined to be the most attractive option and was selected as the optimum energy system and MVP for AOEG to proceed with for the Marketplace design. It optimises the available renewable supplies and achieves lower cost supply from solar and wind, while demonstrating the systemic benefits of wave energy inclusion. A back-up capacity of 30MWh is considered ideal for balancing the system and supporting reliance objectives.

Table 1-1. Scenario Phase 2, Option 2b – installed capacity and reliance on back-up supply

OPTION	SOLAR PV	WIND	WAVE	RESERVE ENERGY
Phase 2 b: Intermediate cost/resilience	28.5 kW	17 kW	5.5 kW	30 MWh

Capital Cost Estimates

The Phase 2b energy system proposes a combined installed capacity for wave, offshore solar and wind energy of 51 kW. A capital cost to construct this installed capacity was estimated by implementing existing cost estimates research by NREL for the installation of smaller generation capacities, similarly to that proposed at the Marketplace. As a result, the total capital expenditure (CAPEX) of A$574,994 is estimated to construct the installed generation capacity and battery storage for the Marketplace, this is summarised in Table 1-2. This is inclusive of contingencies and insurance. Given the cost data used is preliminary and not site-specific, an accuracy range of +/- 40% has been provided to reflect this. An annual average operating cost of A$13,832 has also been estimated using an assumption of 2-3% of CAPEX for each generation type. These cost estimates provide AOEG with an indicative starting point to consider for future funding stages. Undertaking the detailed design of the Marketplace microgrid will be required to gain a bankable cost estimate and provide greater confidence in the Marketplace concept as it matures towards a Final Investment Decision (FID).

Table 1-2. Scenario Phase 2 estimated CAPEX and OPEX by installed renewable generation capacity, unadjusted for inflation.

Renewable Generation Type	Installed Capacity kW	Capex Low (-40%) A$ 2022	Capex A$ 2022	Capex High (+40%) A$ 2022	Annual Opex A$ 2022
Wave	5.5	61,892	103,153	144,414	2,063
Floating Solar	28.5	46,006	76,676	107,346	2,300
Offshore Wind	17	172,157	286,929	401,700	8,608

Battery Storage	25	64,941	108,235	151,529	861
Total	76	344,996	574,993	804,990	13,832

Economic Outcomes

AOEG have established several commercial aspirations for the Marketplace that could enable additional revenue streams throughout the life of the project. Revenue assumptions have been integrated into the economic modelling to understand their impact on the viability of the energy system supporting the Marketplace. Figure 1-4 illustrates the contribution of each revenue stream as well as the Net Cashflow before Tax which includes the initial capital and operating costs for the Marketplace.

As a result, economic modelling suggests the Marketplace has a Pre-Tax Net Present Value of approximately A$1.17 million at a discount rate of 7%. Although outcomes are preliminary and require further materialisation through engaging commercial agreements, they sound out opportunities for AOEG to consider as the Marketplace matures towards FID. Timing of this will likely follow the completion of a definitive renewable resource assessment and detailed design, which will improve the tangibility of the Marketplace.

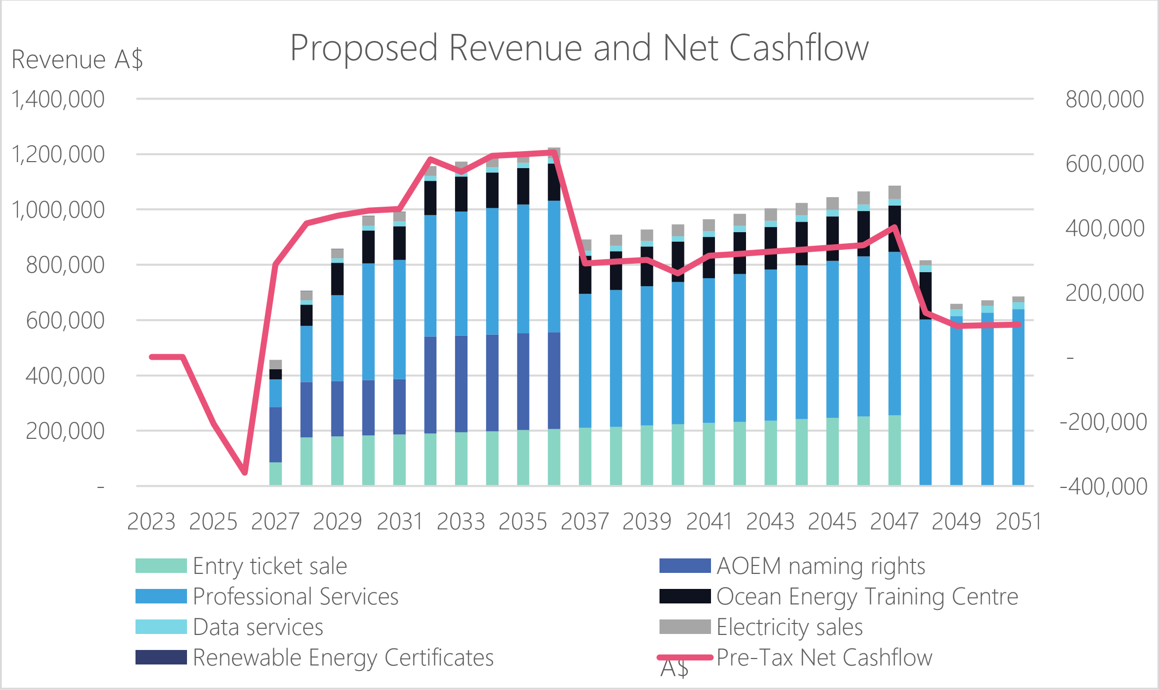


Figure 1-4. Forecasted gross revenue for the marketplace, adjusted for inflation.

Impact Outcomes

In addition to the economic outcomes of the Marketplace operation, it is important that AOEG realise positive impacts on market demand for ocean energy forms. By making ocean energy visible, greater penetration into blue economy markets will improve:

- Awareness – by demonstrating ocean energy technology and how it can provide low carbon solutions to solve market problems;
- Accessibility – allowing markets to see and interrogate a working ocean energy system and model how their bespoke needs could be met;
- Affordability – demystifying the cost benefit curve of ocean energy and a complimentary renewable energy form; and;
- Access to commercial development pathways, including modelling, optimisation and project delivery through professional services offered by Marketplace partners.

By catalysing ocean energy adoption, the Marketplace will contribute to reducing GHG emissions. Through public and private sector education and inclusion in Discovery Bay's tourism offering, AOEG will seek to influence and leverage policy decisions to stimulate wave and tidal energy adoption through economic incentives and subsidies, consistent with historic development trajectories of solar and wind energy.,

Clear economic and impact values have been identified through this technical feasibility study for the Marketplace. However, it should be reiterated that the Marketplace remains in the early stages of its development roadmap – see Figure 7-1. For the Marketplace to move toward value realisation, it is recommended to mature the project concept by undertaking further studies such as:

- Commissioning a field assessment of renewable resources to obtain a complete and granular dataset;
- Detailed design of the generation system will be required;
- Bankable cost estimates
- Mapping those businesses and agencies in the region requiring energy
- Consider local funding candidates

The first two assessments are considered critical for the Marketplace to develop a robust and clear development pathway.

TABLE OF ABBREVIATIONS

ABBREVIATION	EXPLANATION
AC	Alternating Current
AOEG	Australian Ocean Energy Group
ARENA	Australian Renewable Energy Agency
AUD	Australian Dollar
AWAC	Acoustic Wave and Current
CAPEX	Capital Expenditure
CBWC	Cheynes Beach Whaling Company
CCTV	Closed-circuit television
CF	Capacity Factor
CM SAF	The Satellite Application Facility on Climate Monitoring
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DB	Discovery Bay
DEVEX	Development Expenditure
E-Bike	Electric Bicycle
EDA	Electricity Demand Assessment
EMEC	European Marine Energy Centre
EnBW	Energie Baden-Württemberg AG
ETZ	Energy Transition Zone
EV	Electric Vehicle
FPV	Floating Photovoltaic
GWh	Gigawatt-hour
H2	Hydrogen
KW	Kilowatt
LCOE	Levelized Cost of Energy
LCOS	Levelized Cost of Storage
LGC	Large-scale Generation Certificate
LNG	Liquefied Natural Gas
M/S	Meters per Second

ABBREVIATION	EXPLANATION
MERA	Marine Energy Research Australia
MURAL	A digital whiteboard collaborative space
MW	Megawatt
MWh	Megawatt-hour
NASA	National Aeronautics and Space Administration
NEM	National Electricity Market
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
NWIS	North West Interconnected System
NZE	Net Zero Emissions
OE	Operating Expenditure
OEM	Original Equipment Manufacturer
OPEX	Operating Expenditure
ORE	Offshore Renewable Energy
PV	Photovoltaic
QLD	Queensland
RE	Renewable Energy
REC	Renewable Energy Certificate
RRA	Renewable Resource Assessment
SDG	Sustainable Development Goals
SEA	South East Asian
STC	Small-scale Technology Certificate
STEM	Science, Technology, Engineering, and Mathematics
SWIS	South West Interconnected System
TIC	Total Installation Cost
TRA	Technology Readiness Assessment
TRL	Technology Readiness Level
USD	United States Dollar
UWA	University of Western Australia
V&V	Verification and Validation

ABBREVIATION	EXPLANATION
WA	Western Australia
WEM	Wholesale Electricity Market
WSE	Wave Swell Energy

2 INTRODUCTION

The Australian Ocean Energy Group (AOEG) is an industry-led cluster focussed on creating market demand for ocean energy through increased understanding of the potential for Australia's utilisation of ocean energy.

The Australian Renewable Energy Agency (ARENA) defines ocean energy as referring to all forms of renewable energy derived from the sea, starting with wave and tidal, as the main types of ocean technology and also including ocean thermal [1]. For the purposes of this study analysis has been limited to wave and tidal energy, which are the predominant sources of energy from the oceans in Australia.

A key pillar of AOEG's vision is conceptualisation and delivery of an integrated ocean energy microgrid system, currently termed the 'Integrated Ocean Energy Marketplace' (the Marketplace). The Marketplace is seeking to demystify the supply of energy from the ocean estate in Australia and to accelerate market adoption of wave and tidal energy as stand-alone or as part of integrated complimentary renewable systems. It is seeking to develop a market-facing systemic approach to ocean renewables, to stimulate commercial projects and provide a catalyst for accelerated ocean energy adoption.

The Marketplace is proposed to integrate a diverse range of renewable energy generation devices, through a physical control room, and dispatch electricity to provide power to facilities and end-uses such as water purification and battery charging for electric vehicles – See Figures Figure 2-1Figure 2-2.

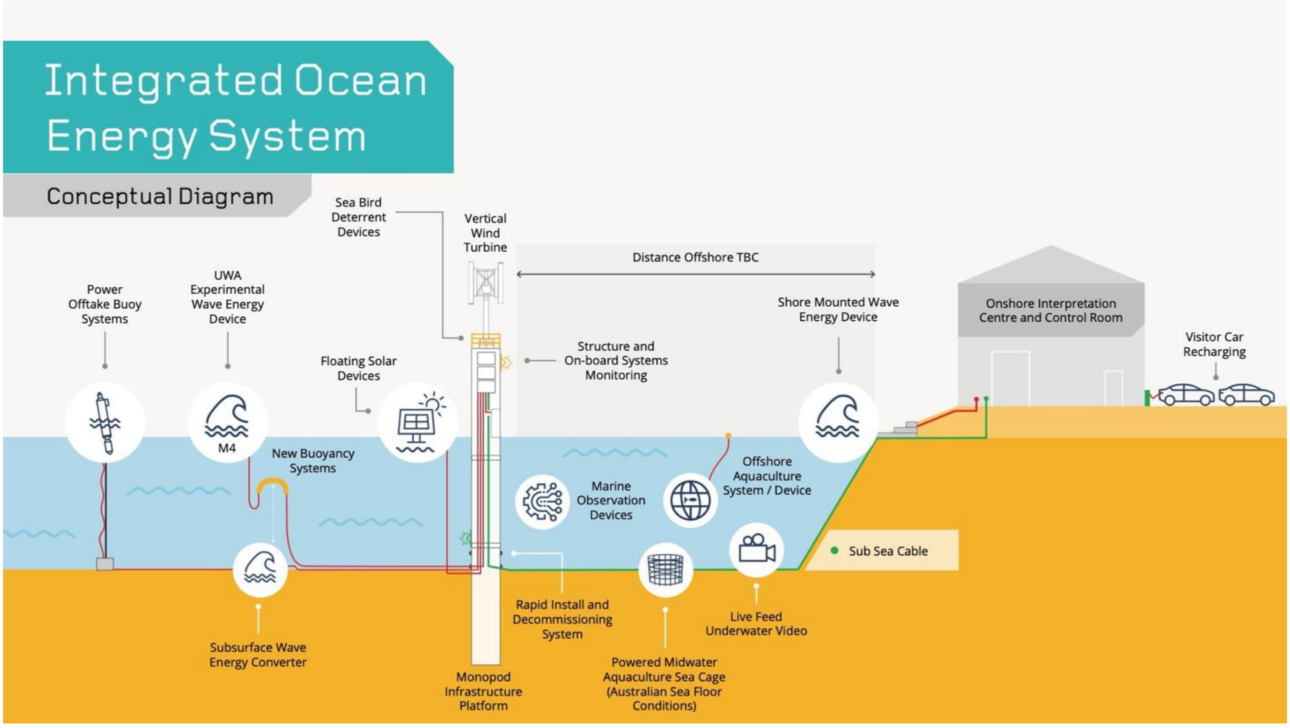


Figure 2-1: Conceptual Diagram of an Integrated Ocean Energy System (AOEG).

Discovery Bay in Albany, Western Australia, a key tourism precinct in the Great Southern Region of Western Australia, is investigating options for improving reliability of its electricity supply. To support design and application of the Marketplace, a non-binding Memorandum of Understanding was signed with Discovery Bay in 2022 as a potential location and real-world customer for electricity provided by the Marketplace.

A key aspect of this partnership is Discovery Bay's ability to embed ocean energy as part of its tourism and educational outreach programs, as a specific attraction to its regional community and wider tourism audience. By creating a public innovation hub in Albany, this exponentially broadens the reach from AOEG's market facing targets to domestic and international travellers, putting ocean energy into the hearts and minds of community, and influencing policy direction.

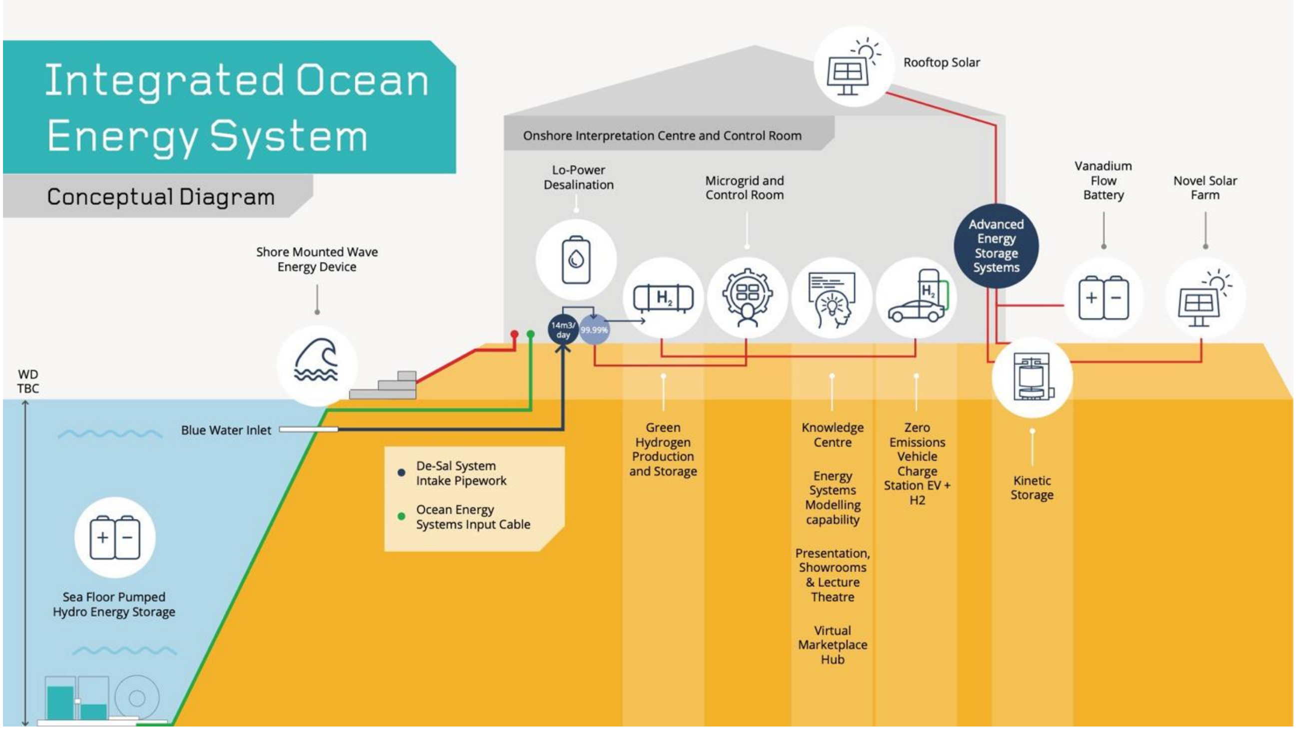


Figure 2-2: Further onshore details of a Conceptual Diagram of an Integrated Ocean Energy System (AOEG).

This report summarises an investigation into the technical viability of the integrated ocean energy microgrid system upon which the Marketplace will be developed. It should be acknowledged that this assessment represents the first stage in the Marketplace development roadmap (see Figure 2-3) and subsequent detailed business and operational analysis will be required.

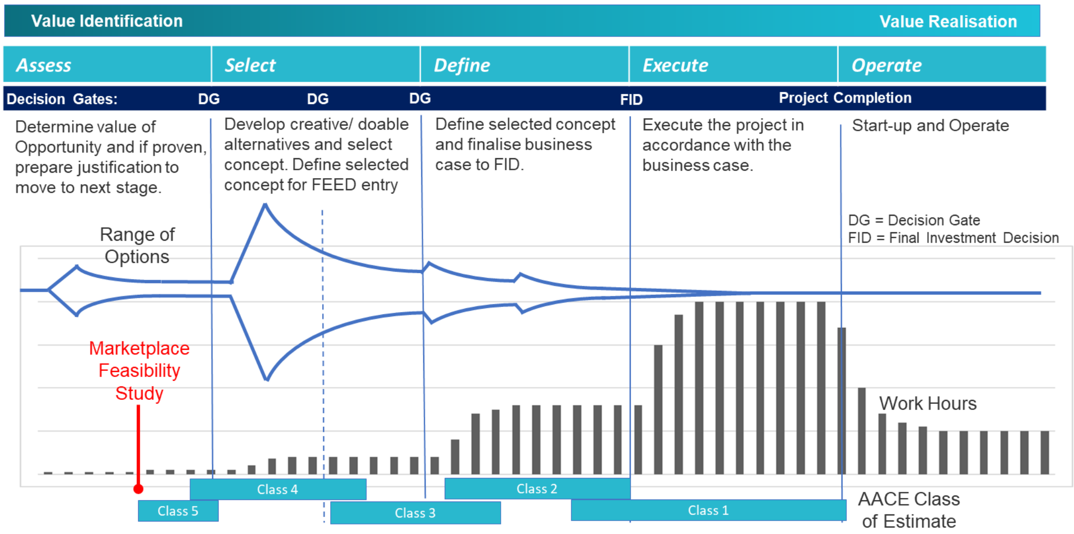


Figure 2-3. General project development roadmap.

3 PROJECT PARTNERS

3.1 The Australian Ocean Energy Group

Australian Ocean Energy Group (AOEG) is a not-for-profit industry-led cluster, established in 2018 to catalyse formation of an ocean energy industry in Australia. AOEG seeks to address the issues of decarbonisation, electrification, reliability, safety and predictability of energy supply through adoption of ocean energy. AOEG is a member-based organisation, bringing together industry, government and academia to provide an effective means to innovate ocean energy solutions, strengthen partnerships, engage stakeholder and align with the industry's focus on growth and investment for wave and tidal energy development.

AOEG's strategic approach to achieve its vision and mission is through implementation of its comprehensive **Ocean Energy Market Development** program, whose aim is to change the ocean energy industry paradigm from 'technology push' to 'market pull'. This program consists of 3 major initiatives:

1. **Gather Market Intelligence (data).** AOEG conducts ongoing ocean energy market assessments to identify and prioritise the markets for wave and tidal energy in Australia and document their requirements for adoption of ocean energy.
2. **Demonstrate Viability (demonstrate).** Establish pilot market-demonstration projects to provide real-life working examples of applications of ocean energy for markets to view.
3. **Ocean Energy Marketplace (deliver).** AOEG's Ocean Energy Marketplace, the subject of this study, is an emerging innovation hub for ocean energy in Albany, WA. The Marketplace will be an integrated ocean energy microgrid combined with a learning and training centre.

.

3.2 Discovery Bay

Albany's Historic Whaling Station is located at Discovery Bay, at the site of the former Cheynes Beach Whaling Company (CBWC), which was the last whaling company to cease operations in Australia, closing in November 1978.

Opening as a historical tourism site in 1980, the facility is now home to an interactive museum on whales and whaling and serves both a tourism and education function, hosting in excess of 50,000 visitors and students each year.

Since conversion in 1980, the precinct has achieved:

- Preservation of all factory buildings and workplaces, including restoration where safety required.
- Relocation of Cheynes IV whalechaser to museum site and full restoration of ship for tourism purposes.
- Twenty enhanced exhibits added, developed with educational objectives, including nine with innovative technology not found in other heritage sites.
- Growth of the business to twenty team members and nine regular volunteers.

The facility includes:

- The main historic whaling station tourism precinct, including various interactive displays
- Galleries and a gift shop
- A cafeteria
- Regional Wildflower Garden
- Australian Wildlife Park
- Operations facilities

At present, the facility accommodates around 55,000 visitors every year, with plans in play to increase product offerings and visitation rates. The Marketplace is seen as an important lever to broaden public interest, enhancing the social, educational and business objectives of the precinct.

Location

Discovery Bay, shown in Figure 3-1, is located 436 kilometres southeast of Perth and a 21-kilometre drive from the city of Albany city. An aerial photograph of the site is shown in Figure 3-2.

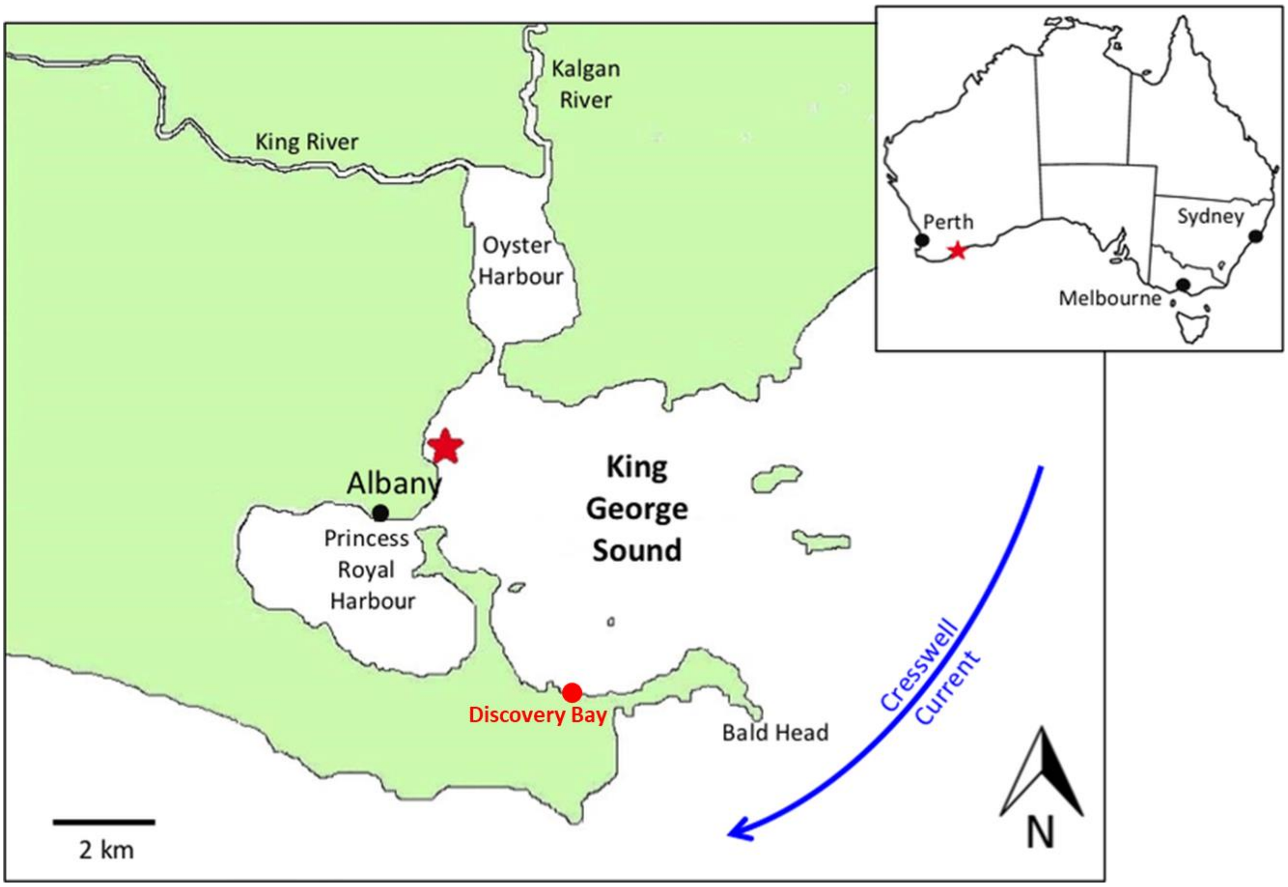


Figure 3-1. Albany's Historic Whaling Station location at Discovery Bay.

Figure 3-2. Aerial view of Albany's Historic Whaling Station location.

3.3 Xodus and X-Academy

Xodus is a global energy consultancy which specialises in ensuring that energy developments are bankable, buildable, and approvable. We specialise in supporting delivery of ocean energy projects and, in Australia, have also delivered offshore and onshore wind, hydrogen, and solar energy projects. Xodus engages with projects through services such as market entry, supply chain, technical feasibility, field design, consenting and development.

X-Academy was established by Xodus in late 2021 with funding from ETZ Limited, bp and EnBW to rapidly upskill passionate people with the knowledge, skills and experience to support the energy transition. Xodus and X-Academy have provided in-kind support to the development of this technical feasibility study.

3.4 Additional Partners

Three additional organisations have made significant in-kind contributions to this project. AOEG's partnership with Marine Energy Research Australia (MERA) has benefited this report following collaboration on the wave energy M4 project. Onetide and OceanPixel have provided strategic support to AOEG with conceptualisation of elements of the Marketplace. All entities also made significant contributions to workshops hosted by AOEG and Discovery Bay in August and November 2022.

3.4.1 Marine Energy Research Australia (MERA)

MERA is an ocean engineering research centre at the University of Western Australia (UWA). MERA headquarters in Albany, South Western Australia, hosts an outreach-focused knowledge and innovation hub for Australia's ocean renewable energy sector and for the region's communities. MERA's facility invites collaborations within academia, marine industry, and government and aims to be a new launchpad for marine research activities in on the WA Southern coast. MERA operates with a mandate to maximise regional re-investment of its external funding, engage regional businesses and deliver economic benefit to the Great Southern.

MERA is a member of the AOEG and has been an active partner in the development of the Marketplace concept. Through collaboration between UWA, the Western Australian Government and the Blue Economy Cooperative Research Centre, MERA is leading the M4 ("Moored MultiModal Multibody") wave energy converter in King George Sound, Albany, which includes worked the Marketplace feasibility study as a project component with 'Royalties for Regions' cash funding to AOEG. A 1/7th scale version of the M4 is scheduled to be deployed in King George Sound in 2023 and will provide an early touchstone for the Marketplace. MERA's M4 project will also begin to test the regional supply chain capabilities and permitting framework for ocean energy developments in the region, which will feed into the Marketplace engineering requirements.

3.4.2 Onetide

Onetide are a Perth-based engineering solutions company in defence, mining, oil and gas, marine logistics, disaster relief and the renewable energy sector. Onetide focus on supplying innovative, rapid deployment engineering solutions in power, water, communications, maritime operations and logistics and essential infrastructure to remote locations. Onetide has supported AOEG with understanding of deploying small-scale stand-alone microgrid systems and technical illustration of conceptual designs.

3.4.2 OceanPixel

OceanPixel are a Singapore start-up company focused on enabling sustainability through data intelligence. The company supports sustainability endeavours primarily in the Southeast Asian (SEA) region with markets such as renewable energy, Blue Economies, and marine big data. The core team has combined professional expertise and innovation experience in the fields of energy, artificial intelligence, big data, sustainability research, development, demonstration, project development and know-how and experience in the relevant industry ecosystems, business, finance, policy and education. OceanPixel have provided AOEG with an understanding of how the Marketplace can utilise digitilisation to support efficiency, innovation and global stakeholder interaction.

4 DEFINING THE MARKETPLACE

The Marketplace concepts seeks to address the objectives of two major stakeholder groups – the needs of the Discovery Bay tourism precinct and the Australian Ocean Energy Group.

4.1 Marketplace Objectives

Discovery Bay and AOEG have separate but complementary objectives.

AOEG is seeking to demystify the supply of energy from the ocean estate in Australia and to accelerate market adoption of, particularly, wave and tidal energy. It is seeking to develop a market-facing systemic approach to ocean renewables, to stimulate commercial projects and provide a catalyst for accelerating ocean energy adoption.

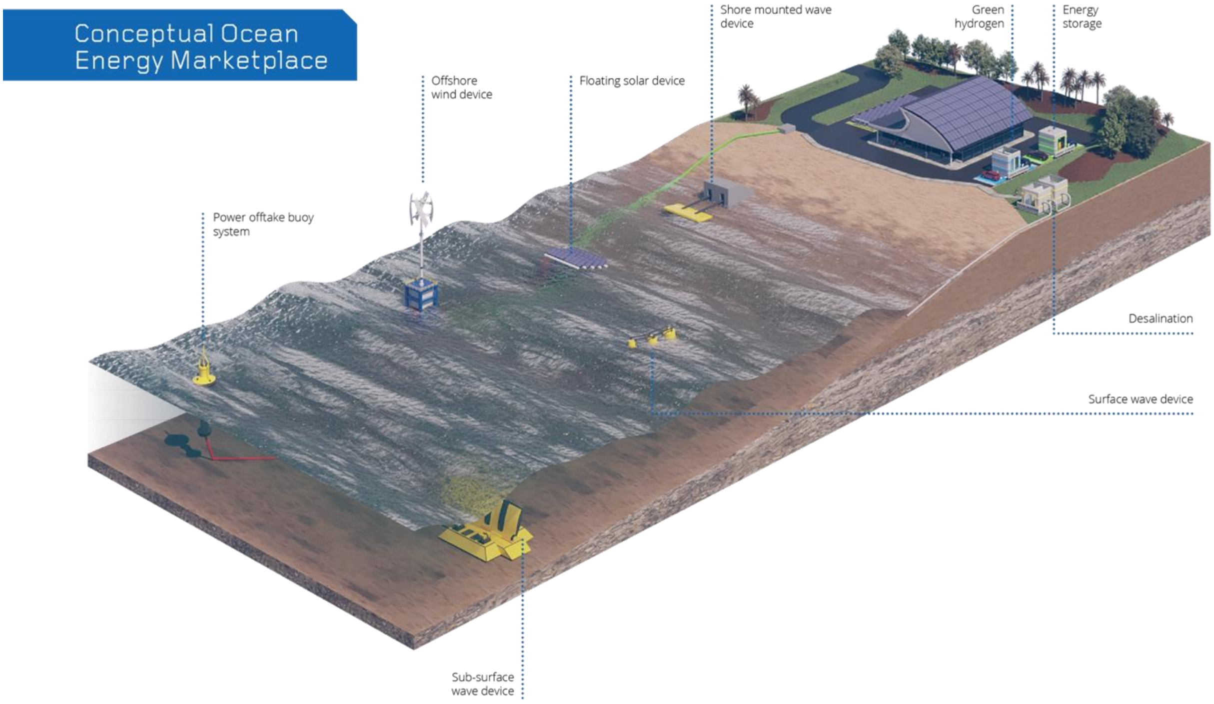


Figure 4-1 Artist's impression of the Conceptual Ocean Energy Marketplace

In addition to a number of business drivers associated with increased tourism opportunities, Discovery Bay are seeking to increase resilience of their energy system, including to understand alternative energy supply opportunities with much of the site's transmission infrastructure requiring replacement within the next five years. They are keen to be first movers in the adoption of ocean energy systems and to embed this technology into their forward looking narrative in respect of responsible tourism and public education.

The Marketplace concept seeks to stitch together a number of key objectives (see Figure 4-2). Importantly, as part of AOEG's mission, a number of soft services are included as key objectives, which primarily seek to raise awareness of the potential for ocean energy and also support commercialisation of ocean energy projects through enhancement of market demand. Discovery Bay's objectives from supporting the Marketplace are aligned with reliability of energy supply and expansion of potential services to attract increased tourism into the precinct.

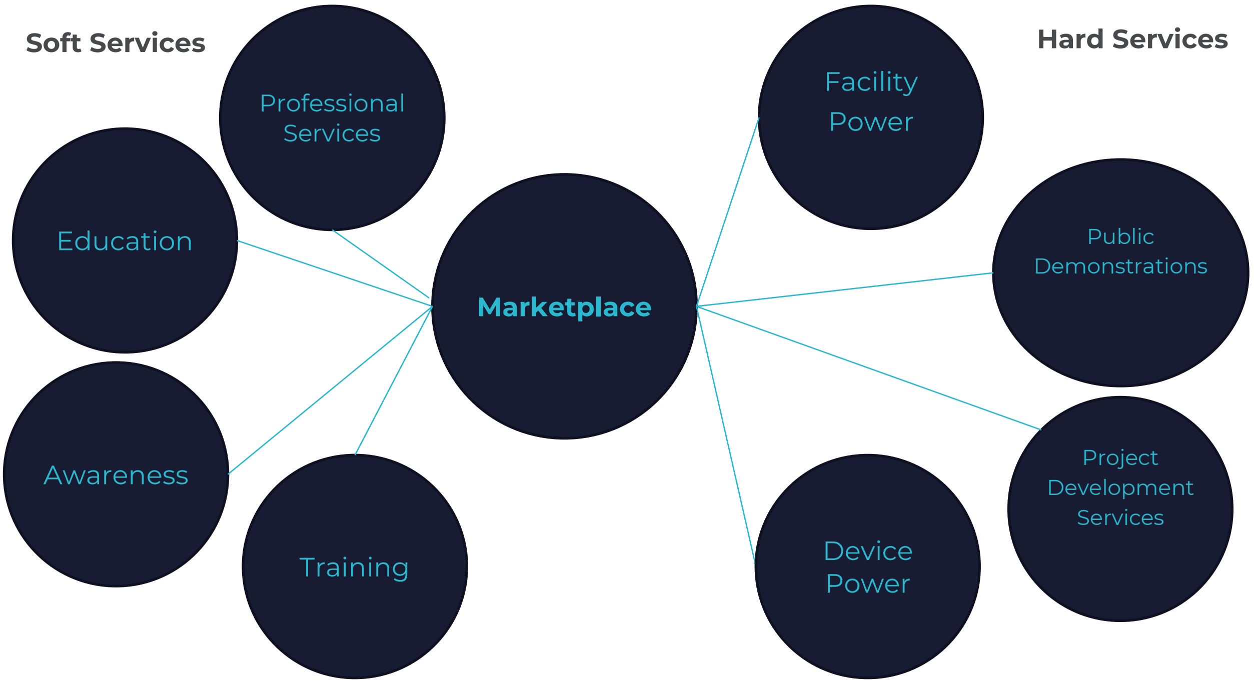


Figure 4-2. Indicative breakdown of various drivers for the Marketplace.

5 AUSTRALIA'S ENERGY CONTEXT

Australia's energy portfolio remains dominated by fossil fuels, but it is on the path of transitioning to low carbon sources. Australia is a significant net energy exporter, comprised primarily of LNG and coal. These exports equate to approximately three times the annual energy Australia consumes domestically. Road transport, mining, and manufacturing sectors accounts for over 58% of domestic energy consumption [3]. The rise of mining and LNG sectors within Australia has notably increased Australia's energy needs within the last 20 years.

Australia's electricity generation is also fuelled majorly by fossil fuels. In 2021, coal and gas accounted for 70% of total electricity generation. Despite its large contribution, this represents a notable decline compared to pre-2010, where fossil fuel electricity generation consistently contributed over 90% of Australia's electricity [4].

Renewable energy is consistently defined as energy that are naturally replenished and do not run out. The application of renewable energy is increasingly competitive with traditional energy forms, such as coal, oil and natural gas. Types of renewable energy include solar, wind, geothermal, hydropower, ocean (wave and tidal) and bio energy. Australia has a significant renewables resource potential that is yet to be fully realised. In 2021, renewables accounted for 27% of electricity generation, primarily from solar PV (40%), onshore wind (35%) and hydro (21%).

Renewables are expected to play a growing role in energy supply going forward and will benefit from scheduled retirement of Australia's ageing coal-fired power generators in states such as New South Wales, Victoria, Queensland and Western Australia.

In particular, Western Australia's South West Interconnected System (SWIS) comprises a unique electricity network. It has a relatively small operational demand compared to its east coast counterpart (the National Electricity Market) but covers an area over 261,000km^2. Currently, more than 52% of the network services less than 3% of users [4]. Over the next decade, Western Power plans to decentralise the SWIS as coal generation retires (see Figure 5-1). Smaller demand centres on the fringe of grid will need to become more reliant on local, stand-alone electricity systems and microgrids [5]. This is the model AOEG seeks to demonstrate in the Marketplace, using a combination of ocean renewable inputs.

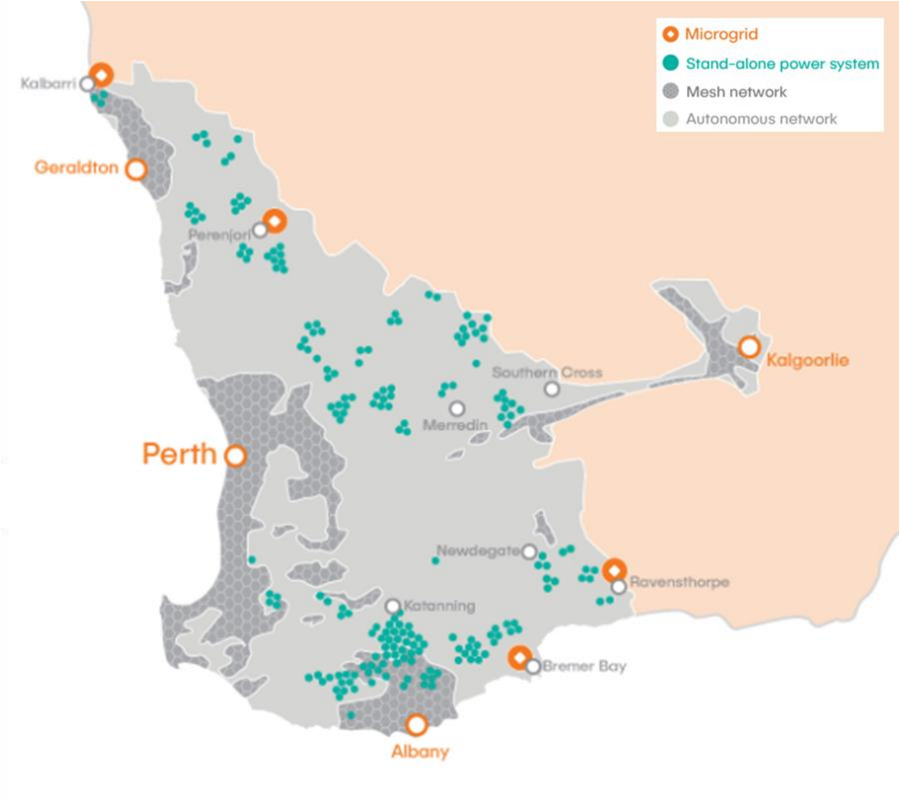


Figure 5-1. The future transformation of the SWIS, adapted from Western Power [5].

5.1 Existing Energy Network

Infrastructure

The Wholesale Electricity Market (WEM) stands independent from the National Electricity Market (NEM) and is primarily composed of the South West Interconnected System (SWIS) and the North West Interconnected System (NWIS).

The WEM involves several utilities and generators, as outlined below:

- Synergy
- Western Power
- Horizon Power

The WEM first became functional in 2006 and provides electricity through the 260,000 square km-strong transmission network of the South West Interconnected System (SWIS), of which the majority represents distribution lines.

Unlike its counterpart for eastern and south-eastern Australia, the National Electricity Market (NEM), the SWIS is not connected to any other major transmission network, making it one of the most isolated in the world, with implications for connected electricity generators and consumers. The SWIS is divided into eleven transmission network zones (or nodes) and each substation, point load, generator and storage facility on the network was allocated to one of the nodes, as depicted in Figure 5-2. The AOEG Integrated Ocean Energy Marketplace is proposed at the very fringe of the South East transmission network zone.

Figure 5-2. Map of the SWIS and the transmission network zones (nodes).

The Albany network is located within the South West node and its network infrastructure owned by Western Power. As illustrated in Figure 5-3, Discovery Bay is located at the southern extent of the Albany network on the fringe of the grid. Its access to electricity relies on a single-phase overhead transmission line, this is depicted in Figure 5-4. Discovery Bay have indicated that these transmission lines connecting businesses to the grid would require upgrade within the next 5 years. Discovery Bay is undertaking a cost-benefit analysis of remaining on the grid, to which this report will contribute.

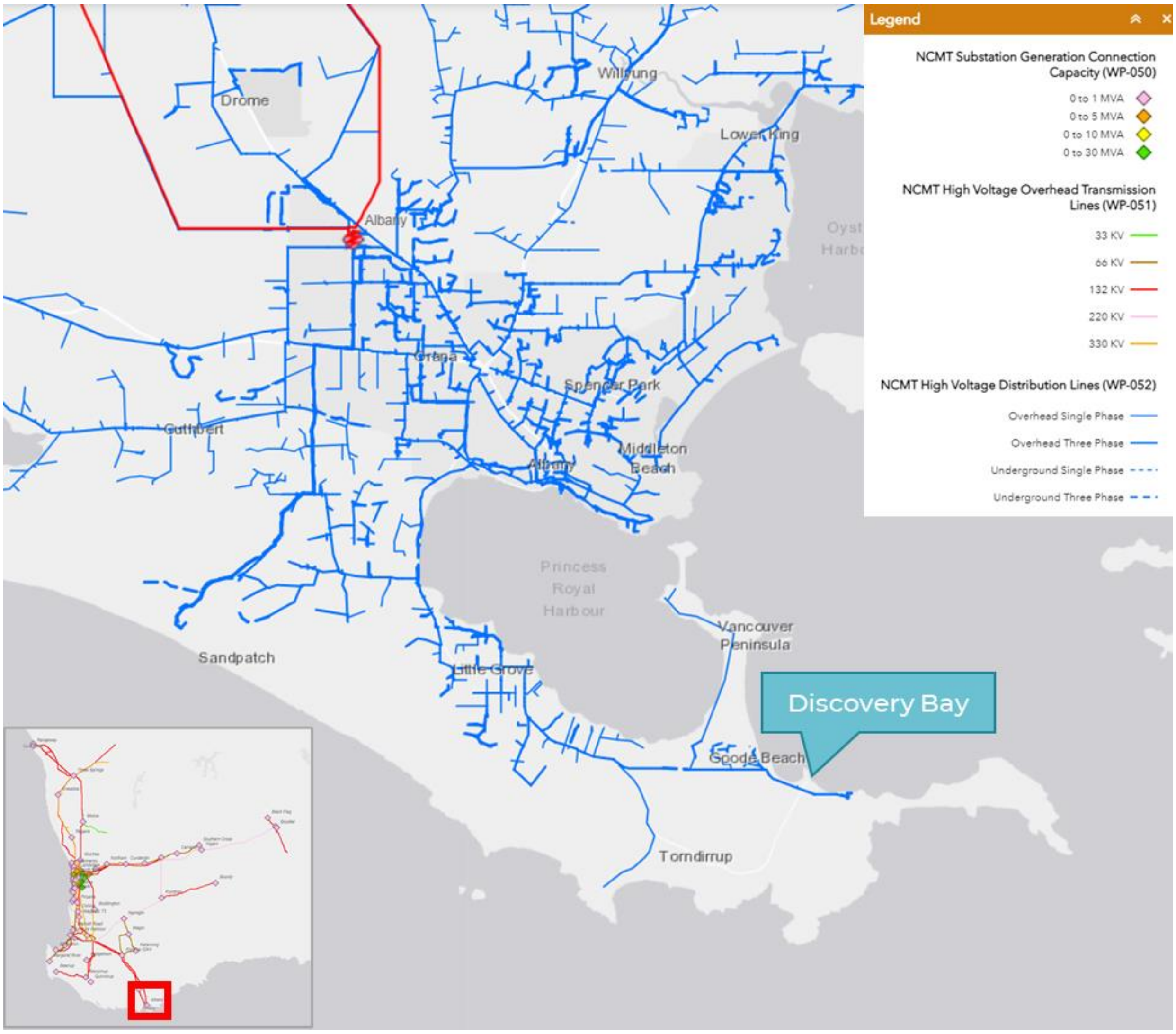


Figure 5-3. Albany Region Electricity Network [modified from Western Power Network Capacity Mapping Tool [6]].

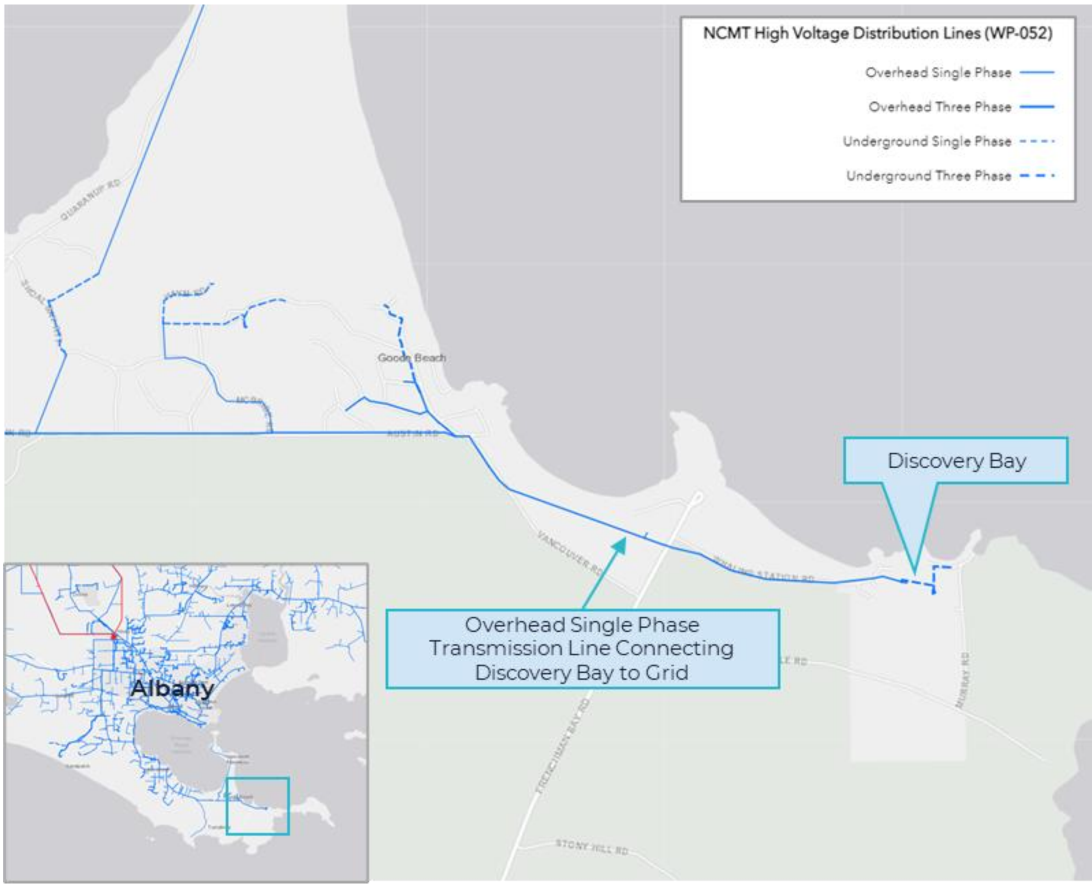
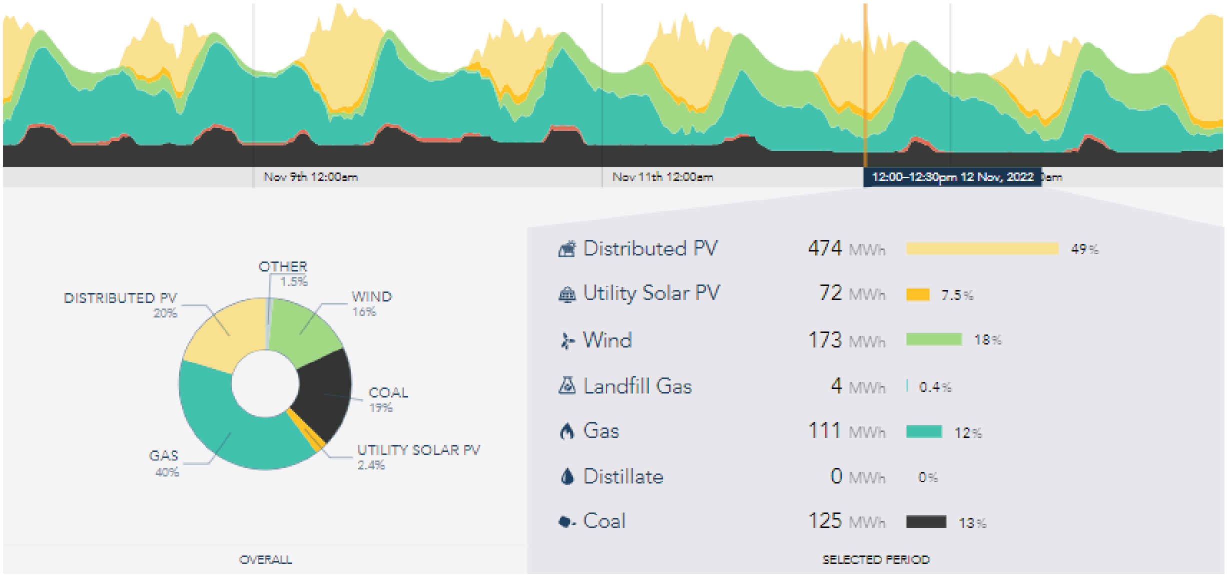


Figure 5-4. Discovery Bay Electricity Network Access [modified from Western Power Network Capacity Mapping Tool [6]].

5.2 Energy Supply

A diverse range of fuel types currently contributes to electricity generation for the SWIS. Figure 5-5 illustrates the electricity mix of the SWIS during one week in November 2022. Onshore Wind, Distributed and Utility Solar PV have met ~38% of electricity demand. The SWIS heavily relies on coal and gas power generation given the limitations of solar in meeting certain daily peak demand intervals.



Distributed PV	474 MWh	49 %
Utility Solar PV	72 MWh	7.5 %
Wind	173 MWh	18 %
Landfill Gas	4 MWh	0.4 %
Gas	111 MWh	12 %
Distillate	0 MWh	0 %
Coal	125 MWh	13 %

Figure 5-5. SWIS weekly (top and left) and 12th November 2022 midday (right) electricity generation by energy type [7].

Supply Disruption

Historically, Discovery Bay and its surrounding area has experienced both planned and unplanned power outages. These power outages have become more frequent as Discovery Bay's services and visitation have grown.

In addition to having an adverse effect on corporate diversification and expansion initiatives, outages have a disproportionately negative effect on Discovery Bay, a medium-sized company and a major tourist attraction in the area. it can lead to spoilage of food held in cool storage at the café, prevent operation of safety features (such as lighting), prevent operation of the tourism precinct and events, interfere with life support systems for the wildlife sanctuary, and impact the financial and reputational stability of the business. The inability to do business as usual as a result of these external factors is a major justification for Discovery Bay to look for a more dependable energy supply and is indicative of the common challenges faced by fringe of grid businesses

Planned outages are frequently communicated to Discovery Bay. In these situations, Discovery Bay must employ portable diesel generators to maintain regular commercial operations and supply electricity to the on-site facilities.

Unplanned outages do not provide advance notice to Discovery Bay, making it challenging to arrange alternative power supply. As a result, the business is unable to carry out regular operations and is forced to close to the public. This would necessitate cancelling reservations for individual visitors and scheduled group tours, resulting in loss on food stocking and meal preparation cost as well as higher staffing costs. There would also be an increased likelihood that individuals and groups would not reschedule or book additional visits. This has a negative impact on Discovery Bay's revenue as well as its organisational, stakeholder, brand, and financial reputations.

Local Markets

Discovery Bay is representative of and shares the energy security issues described above with many similar businesses and agencies in the Great Southern region.

Water supply is also a market to consider. Over the last 20 years, a decrease in winter rainfall in the regions of Western Australia, including parts of the Great Southern region, has contributed to a reduction in inflow into many surface dams. The town of Denmark, for instance, formerly relied on rainfall feeding into the neighbouring Quickup Dam for drinking water year-round. Climate change has had an impact on this water source as well. Denmark is now linked to the Lower Great Southern Towns Water Supply Scheme by a 43 km pipeline, which will help the town's supply be secure in the long run. Albany, Mount Barker, Kendenup, Narrikup, and many other communities receive water from this network of underground pipes. The need to minimise the cost of compliance with environmental regulations, as well as the region's residents' rising reliance on alternative water collection techniques like desalination, were also brought up by stakeholders. [8]

In addition, opportunities for water recycling are being prioritised throughout the region, especially in Albany, where a tree farm there uses 2,000 million litres of treated wastewater annually to support over a million trees while also removing 70,000 tonnes of carbon from the atmosphere.

Mapping those businesses and agencies in the region requiring energy, including those carrying out water desalination and wastewater treatment and aggregating their demand would help quantify the market potential – this is currently out of the scope of this study but could be considered in the future.

5.3 Significance of the Marketplace to Australia’s Energy Transition (Blue Economy Markets)

Australia has the potential to benefit from the development of ocean energy, as the majority of Australia’s urbanisation is constrained to coastal settings. Consequently, over 85% of Australia’s population resides 50km from the coast. There is a significant opportunity for ocean energy to complement the development of well-known renewable resources, such as solar and wind energy, to support the broader energy transition within Australia. AOEG’s proposed Integrated Ocean Energy Marketplace could provide a real example of ocean energy deployment and catalyst for coastal communities with similar energy challenges to investigate its potential on their respective coastline.

As described in Chapter 5, electricity networks across Australia will be re-designed to accommodate greater renewable energy as coal electricity generation and broader fossil fuels are removed from the energy mix. These reforms will have greater consequences for regional communities with smaller demand centres that are located off-grid or on the fringe of grid.

Off-grid demand centres likely to already utilise renewable resources such as solar and wind energy, but also require gas or diesel power generation to build greater system resilience. Communities that rely on this type of energy security will eventually need to seek alternatives to fossil fuel power generation for system resilience.

Fringe of grid demand centres typically rely on the grid transmission networks to send central large-scale electricity supply to the end of the grid. Grid reforms will seek to remove transmission networks connecting small demand centres by such long distances. Standalone and local electricity supply will be desirable for small regional demand centres, rather than receiving electricity from a centralised generation system. By developing ocean energy in parallel with solar and wind for off-grid and fringe of grid demand centres, greater system resilience and lower reliance on gas or diesel generation could be achieved.

Figure 5-6 illustrates Australia's population, transmission and electricity generation distribution. It is evident that not all population concentrations overlay existing grid or generation infrastructure, and the electricity security challenges that AOEG's proposed Integrated Ocean Energy Marketplace is addressing may exist elsewhere. Most notably, the populations on the southern coasts of Western Australia (Figure 5-7), South Australia (Figure 5-8) and Victoria could benefit from the advancement in ocean energy. Historical population data also indicates sizeable growth in significant urban areas over the last 20 years, as depicted in Figure 5-9. A number of these areas are located off grid or fringe of grid.

Based on these key points, the Integrated Ocean Energy Marketplace, proposed by AOEG would provide a very important catalyst for other analogue demand centres to consider ocean energy as part of their energy solution. The development of new energies is not linear and requires first movers showcase the benefits of alternative options and form the foundations that others build on.

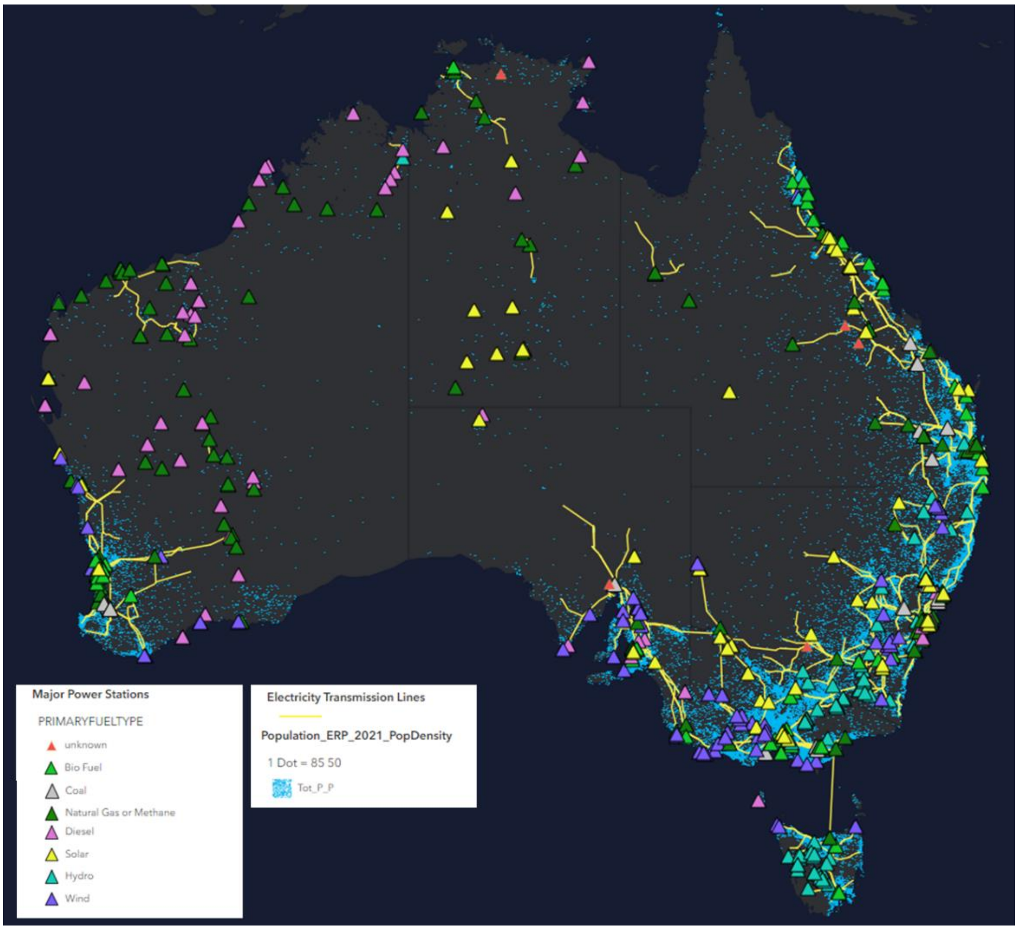


Figure 5-6. Australian population density, electricity grid and power generation.

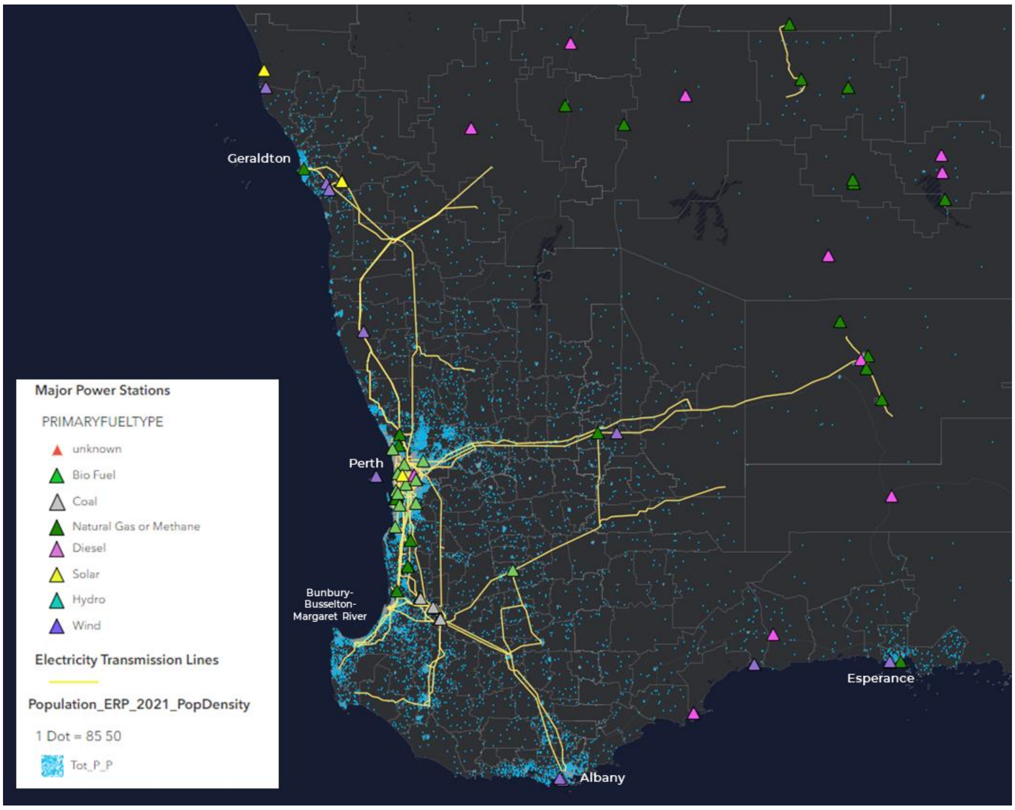


Figure 5-7. South-Western Australian population density, electricity grid and power generation.

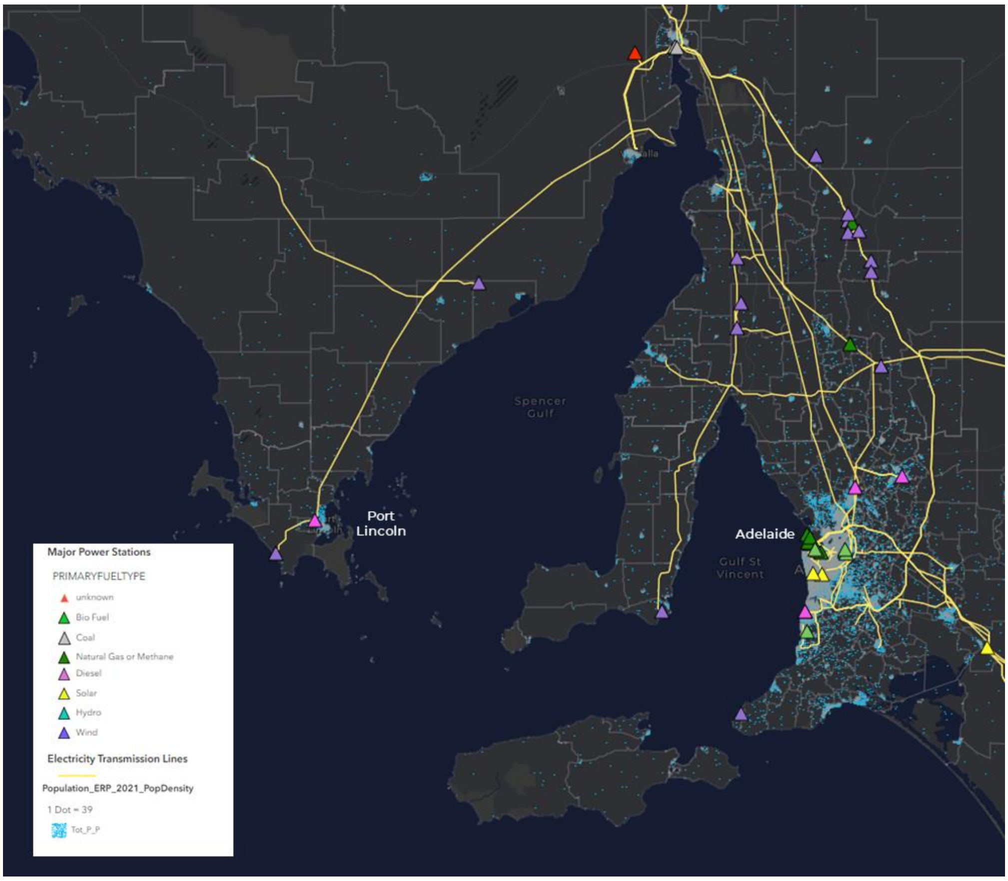


Figure 5-8. Greater Adelaide population density, electricity grid and power generation.

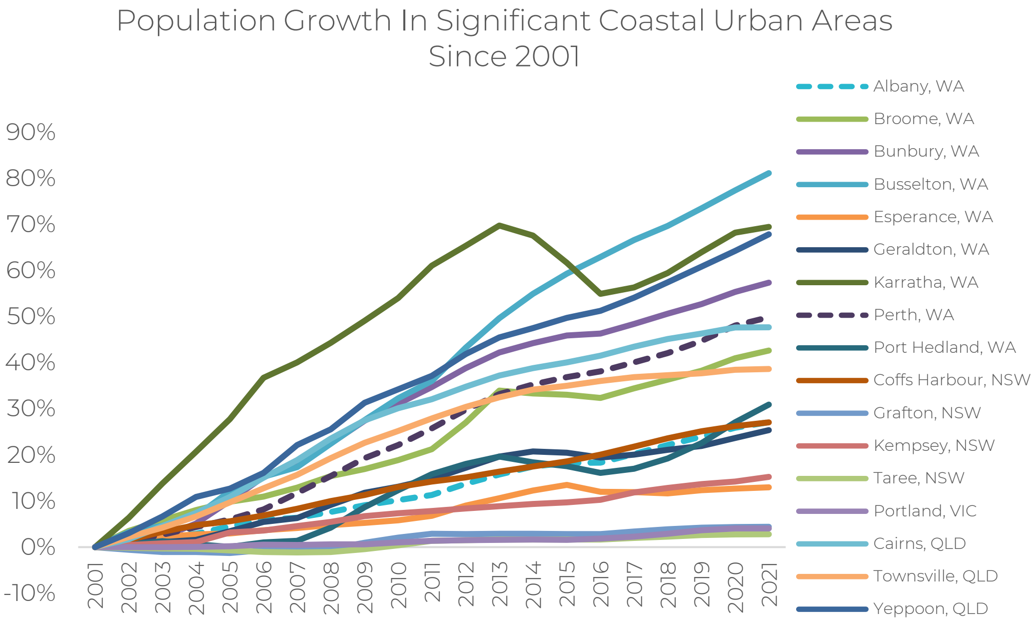


Figure 5-9. Population Growth in Significant Coastal Urban Areas of Australia [41].

6 POWER STRATEGY

This section provides an overview of the readiness of technology to be deployed, the potential renewable resources available and the potential supply and demand scenarios at the project site. It assesses and describes the way in which renewable energy might be supplied and consumed by the Marketplace and its customers.

6.1 Methodology Overview

In order to assess the suitability of renewable power technologies within an energy system designed for Discovery Bay, four main steps were taken, as described below:

a. **Technology review:** Evaluation of the maturity of renewable power and energy storage technologies, and their suitability in the context of Albany's renewable energy resources.
b. **Renewable resource assessment:** Characterisation of the available renewable energy resources proximate to Discovery Bay. Outcomes from the assessment are used to identify the renewable power technologies that are technically viable in the region.
c. **Discovery Bay (and surrounds) demand assessment:** Characterisation of the likely future electrical demand of Discovery Bay and associated demand sources. Outcomes from the assessment are used to form five different demand scenarios, that consider different levels of added demand on current levels.
d. **Energy system modelling:** Energy modelling simulations undertaken to establish the performance of renewable power and energy storage technologies within energy systems designed specifically for the five future Discovery Bay demand scenarios. The energy system modelling considers how renewable power and energy storage technologies can be combined to optimise the energy system design for a range of objectives, including cost of energy, system resilience and the demonstration of offshore renewables, noting the limitations of the relatively low energy wave resource at the King George Sound location.

In this section of the report these three steps are described, with an overview of the methods adopted and results gained to inform the future energy system design.

6.2 Technology Review

"Renewable energy technologies" is an umbrella term that stands for energy production using a renewable energy source, can also be known as "renewable energy systems" and ultimately represents the actual power plant that converts the renewable energy carrier or source into electrical, mechanical and/or thermal energy for use by the consumer [9].

Renewable energy technologies offer a wide range of solutions to capture, transform and provide energy and as such the various technologies differ in respect of where they are in terms of their development. Understanding the maturity and viability of deployment of these technologies is paramount to planning and integrating them to energy systems. To assess the technical maturity of each proposed technology, the Technology Readiness Level (TRL) index is normally used. The study developed a technology review table that includes TRL prior to quantifying energy resources available in Albany and carrying out yield calculations in subsequent sections.

6.2.1 Technology Readiness Level Concepts

The technology readiness level (TRL) index is a globally accepted benchmarking tool for tracking progress and supporting development of a specific technology through the early stages of the technology development chain, allowing for a consistent comparison of maturity between different types of technologies. TRL assessments aid in providing a common understanding of each technology status, managing risks of technology development and making decisions concerning technology funding and deployment.

Table 6-1. ARENA technology readiness levels [10].

LEVEL	SUMMARY
1	Basic principles observed and reported: Transition from scientific research to applied research. Essential characteristics and behaviours of systems and architectures. Descriptive tools are mathematical formulations or algorithms.
2	Technology concept and/or application formulated: Applied research. Theory and scientific principles are focused on a specific application area to define the concept. Characteristics of the application are described. Analytical tools are developed for analysis of the application.
3	Analytical and experimental critical function and/or characteristic proof of concept: Proof of concept validation. Active research and development is initiated with analytical and laboratory studies. Demonstration of technical feasibility using breadboard implementations that are exercised with representative data.
4	Component/subsystem validation in laboratory environment: Standalone prototyping implementation and test. Integration of technology elements. Experiments with full-scale problems or data sets.
5	System/subsystem/component validation in relevant environment: Thorough testing of prototyping in representative environment. Basic technology elements integrated with reasonably realistic supporting elements. Prototyping implementations conform to target environment and interfaces.
6	System/subsystem model or prototyping demonstration in a relevant end-to-end environment: Prototyping implementations on full-scale realistic problems. Partially integrated with existing systems. Limited documentation available. Engineering feasibility fully demonstrated in actual system application.
7	System prototyping demonstration in an operational environment: System prototyping demonstration in operational environment. System is at or near scale of the operational system with most functions available for demonstration and test. Well integrated with collateral and ancillary systems. Limited documentation available.
8	Actual system completed and qualified through test and demonstration in an operational environment: End of system development. Fully integrated with operational hardware and software systems. Most user documentation, training documentation, and maintenance documentation completed. All functionality tested in simulated and operational scenarios. Verification and Validation (V&V) completed.
9	Actual system proven through successful operations: Fully integrated with operational hardware/software systems. Actual system has been thoroughly demonstrated and tested in its operational environment. All documentation completed. Successful operational experience. Sustaining engineering support in place.

There are various TRL rating scales that may be applicable to various technologies. This document has used the same TRL rating scale that ARENA applies for renewable energy technologies [11]. The scale categorises the stages of the technology development chain, from blue sky research (TRL1) to actual system demonstration over the full range of expected conditions (TRL9), increasing as maturity increases. The ARENA TRL Scale is detailed in Table 6-1.

TRL is determined during a technology readiness assessment (TRA) that examines the attributes and demonstrated capabilities of a technology in regard to the sentences on the summary part of a specific TRL scale as in Table 6-1.

6.2.2 Technology Review – Renewable Energy Generation

Prior to quantifying the energy resources available in Albany and carrying out yield calculations, it was decided to review, as a go no go step, a list of renewable energy generation technologies relevant to the client and the proposed site. Such review, summarised in Table , placed the technologies in 4 subgroups according to their guidance Levelized Cost of Energy (LCOE) costs [12, 13, 14, 15] and assessed maturity by the study. Expected capacity factors (CF) were also shared - CF is the ratio of the actually produced electrical energy to the electrical energy that could have been produced at continuous operation at full power output during the same period [16].

Onshore Solar PV (large) and Onshore Wind Turbine were identified as being the lowest cost and highest maturity for the site, followed by Floating Solar PV (large) with still low costs but not such a high maturity. On a quite separate tranche, Offshore Wind Turbine had medium costs with varying maturity depending on whether it would be fixed bottom (high) or floating (medium). Floating Wave and Bottom Fixed Tidal were identified as potentially being high costs with medium maturity. Barrage Tidal was not included in the analysis given its large infrastructure cost.

It is important to highlight that at this stage, no technology was excluded from subsequent analyses (besides ocean thermal devices as explained in the Introduction). Given a key objective of AOEG is to encourage the use of marine energy and to demonstrate its value in grid stabilisation when combined with more mature renewable technologies, it is important to carry higher cost generation options forward and assess their technical feasibility and appropriateness to the selected site.

6.2.3 Technology Review – Energy Storage

While energy balancing will be carried across various generation technologies, it could be expected that energy storage would play an important role on enhancing reliability of supply in the absence of a way to import additional energy from the grid. As another go no go step, a list of energy storage generation technologies was reviewed (including their suitability for integration) and summarised in

. The review resulted in a clear divide between battery storage, with the cheapest cost and high maturity, and every other option.

At this stage, only battery storage (Lithium Ion or Vanadium) warranted further study for integration into the Marketplace. Other options were excluded on the basis of very high costs, not being suitable to Albany (e.g., using plenty of water), low TRL or requiring a material change of focus for the project (e.g., underground storage), but may still be valid inclusion at pilot scale to meet demonstration objectives.

Table 6-2. Technology review - renewable energy generation. Sources include the GenCost 2021-22 Final report from CSIRO [12], 2019 Cost of Wind Energy Review from NREL [13], Wave energy cost projections from CSIRO [14] and the ORE Catapult Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit Study [15].

TECHNOLOGY	ESTIMATED STUDY TRL	GUIDANCE LCOE	EXPECTED CAPACITY FACTOR (CF)	ADVANTAGES	DISADVANTAGES	RECOMMENDED DEVICES
Onshore Solar PV-(large)	9	44-65 A$/MWh [12]	0.32-0.22 [12]	• Low maintenance costs and long life	• High upfront costs • Shading can cause losses	Q-Cells Q.Pro G3 Solar Panels (250 and 315 W) JA Solar 325W Mono MBB Percium Half-Cell All Black MC4 Delta or GivEnergy Inverters
Floating Solar PV (large)	7-8	53-78 A$/MWh [12]	0.33-0.22 [12]	• Pressures on land use are relieved • Higher power generation due to water cooling effect • Shade avoidance	Higher costs that onshore solar (e.g. sealed panels, racking system in water, etc.) Not yet deployed on large-scale	Ocean Sun GCL-SI Those used by Oceans of Energy
Onshore Wind Turbine	9	44-65 A$/MWh [12, 13]	0.35 [12]	Less expensive than offshore wind Shorter cables so less voltage drop	Potential wind blockages due to surrounding landscape Visual and sound impact Potential interactions with birds Small size turbines tend to have much lower CF than larger turbines	Vestas V80/2000kW Enercon (various) Nordex (various) Bonus (various)
Offshore Wind Turbine – Fixed Bottom	9	128-166 A$/MWh [12, 13]	0.35 [12]	Higher power than onshore Reduced visual and sound impact which allows for bigger turbines Pressures on land use are relieved	Longer length of cables and weathering so higher costs Potential interactions with birds Small size turbines tend to have much lower CF than larger turbines	Vestas V80/2000kW
Offshore Wind Turbine – Floating	8-9	198 A$/MWh [13]	N/A	• Can be deployed in deeper waters • Same as above	• Higher costs than fixed bottom • Same as above	Vestas V80/2000kW
Floating Wave Technology	4-6	480 A$/MWh [14]		• More predictable and reliable than wind	• The amount of energy transported through waves does vary every year and from season to season • Not yet deployed on large-scale, thus still high costs	Corpower Aquabuoy M-4 Wave Swell Energy (WSE) UniWave
Bottom Fixed Tidal	4-7	532 A$/MWh [15]	N/A	• More predictable and reliable than wind • Higher density of water so higher power extraction than wind for the same speed of medium	• Intermittency • Potential interactions with marine life • Higher loads on the equipment so potential higher costs • Not yet deployed on large-scale, thus still high costs	Not yet determined (e.g. MeyGen)

Table 6-3. Technology review - energy storage. Sources include Kebede et al paper [17] and the Schmidt et al study from Joule [18].

CATEGORY	TECHNOLOGY	TRL [17]	GUIDANCE LCOS [18]	NOTES	MARKETPLACE INTEGRATION?	RECOMMENDED BRANDS
Electrochemical	Lithium Ion Battery	9*	455 A$/MWh	• (Lithium) Nickel Manganese Cobalt Oxide and (Lithium) Iron Phosphate types	• Yes	GivEnergy Tesla
Ions moving between electrodes	Vanadium Redox Flow Battery	9	390 A$/MWh	• Flow type of battery	Yes	Not yet identified
	Lead Acid Battery	9	2,273 A$/MWh	Potentially larger environmental impact	No	Not applicable
Chemical Using chemical reactions to store energy	Green Hydrogen	6-7*	2,760 A$/MWh	Store energy as hydrogen that then gets used in a fuel cell	No	Not applicable
Mechanical	Flywheel	6	982 A$/MWh	• Rotational kinetic energy • Useful when continuously generating/consuming energy	• No	Not applicable
Using gravitational potential, kinetic or compressed energy	Compressed Air Storage	4	861 A$/MWh	• Requires underground storage (large) • For large capacity/utility size	• No	Not applicable
	Pumped Hydro	9	406 A$/MWh	• Water gravitational potential energy (two reservoirs thus requiring plenty of water) • For large capacity/utility size	• No	Not applicable
Electrical No energy conversion	Supercapacitor	4	2,435 A$/MWh	Also called double-layer or ultra capacitors • Use of electrostatic field	• No	Not applicable

6.3 Renewable Resource Assessment

The following section details findings from the renewable resource assessment undertaken for the proposed project site at Discovery Bay, Albany WA. The assessment focuses on delivering the following:

- Identifying renewable energy potential, using publicly available wind, solar, wave and tidal stream resource data resource from the project site. This includes characterisation of the temporal variability in each of the renewable resources, at annual, seasonal, and hourly time scales.
- Characterise the temporal variability in the renewable resources.
- Establish the complementarity of different renewable resources, that can be utilised to balance supply with demand and reduce reliance on reserve power supply.

6.3.1 Solar Resource

Background

Australia has some of the world's largest solar resource; the Australian continent has the highest solar radiation per square metre of any continent [19]. Albany's location on Australia's south-west coast result in it seeing an average of 6 sunshine hours, daily, while the Australia's north-west coast receive an average of 10 sunshine hours daily [20].

Solar irradiance is a variable and intermittent resource. While varying across day and night, and intermittent due to cloud cover, there is an element of predictability in both monthly and hourly solar irradiance resource.

Annual Variability

Figure 6-1 illustrates the annual mean solar irradiance for the period 2001 to 2020 at Discovery Bay. The annual mean solar irradiance ranges from a maximum of 0.222 kW/m^2 in 2019 to a minimum of 0.209 kW/m^2 in 2001. The mean solar irradiance of 0.215 kW/m^2 over the whole period is included for comparison. The range of annual mean wind speeds represents a ±6% variation. This annual variability is taken into account in our energy system modelling, by running simulations over this 20-year time period.

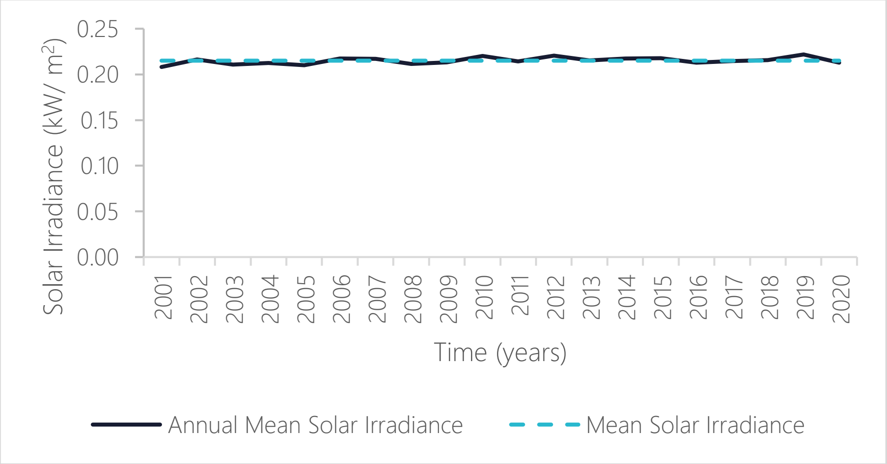


Figure 6-1. Annual mean solar irradiance at Discovery Bay, 2001-2020.

Monthly Variability

Figure 6-2 shows the monthly mean solar irradiance at Discovery Bay for the period 2001-2020. The monthly mean solar irradiance ranges from a maximum of 0.294 kW/m^2 in January to a minimum of 0.123 kW/m^2 in June. The mean solar irradiance of 0.215 kW/m^2 is included for comparison. The range of monthly mean solar irradiance represents an 82% variation, explained by the difference in summer solar resource and winter solar resource.

Monthly mean solar irradiance on-site follows an expected pattern; the summer months provide the greatest solar irradiance while the winter months provide the least solar irradiance.

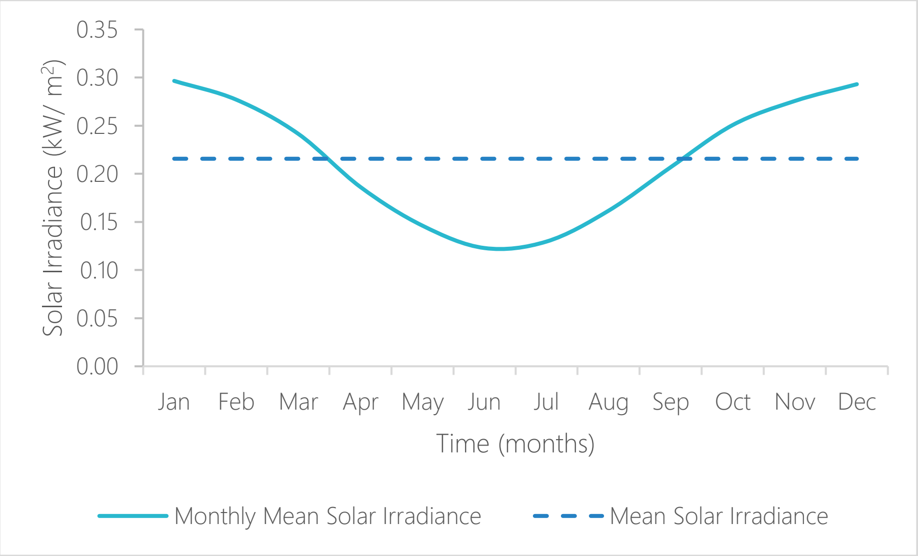


Figure 6-2. Monthly mean solar irradiance at Discovery Bay, 2001-2020.

Hourly Variability

Figure 6-3 illustrates hourly mean solar irradiance at Discovery Bay for the period 2001-2020. January and June are highlighted as examples of greatest and least solar irradiance across the year.

During January, solar irradiance is available between 0500hrs and 1900hrs, peaking at 1200hrs with 0.918 kW/m^2; during June, solar irradiance is available between 0700hrs and 1700hrs, peaking at 1200hrs with only 0.498 kW/m^2. Peak mean hourly solar irradiance occurs at 1200hrs with 0.729 kW/m^2.

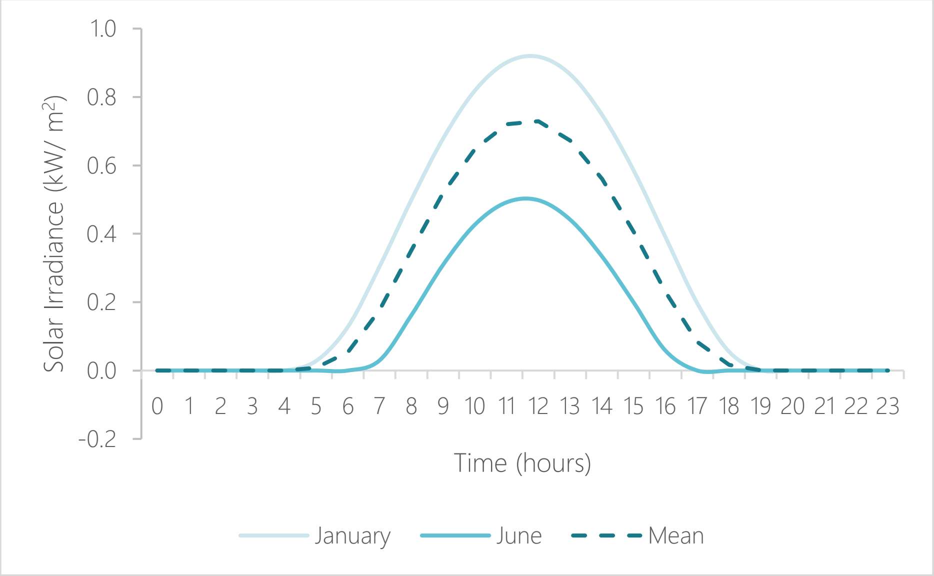


Figure 6-3. Hourly mean solar irradiance at Discovery Bay, 2001-2020.

Assessment of Solar Resource

The solar resource assessed at the proposed project site provides a good mean solar irradiance value in general. Table 6-4 provides a summary of the solar resource assessment. A mean solar irradiance value of 0.167 kW/ m^2 is a suggested minimum value when considering solar PV; this value is exceeded by 25% at this site when assessed as mean annual and mean monthly values.

The nature of the solar resource is that seasonal variation is to be expected. Figure 6-2 illustrates that seasonal variability on-site as the summer months receive greater solar irradiance than the winter months. This winter reduction in solar resource could be mitigated by increases in other renewable resources such as wave or wind.

Table 6-4. Summary of solar irradiance data.

	MEAN (kW/m^2)	MAX. MEAN (kW/m^2)	MIN. MEAN (kW/m^2)	RANGE (%)
ANNUALLY	0.215	0.222	0.209	6
MONTHLY	0.215	0.294	0.123	82
HOURLY (JAN)	0.300	0.918	0.00	N/A
HOURLY (JUN)	0.120	0.498	0.00	N/A

6.3.2 Wind Resource

Background

Wind is a variable and intermittent resource, fluctuating at timescales ranging from minutes to hours, over days, weeks, and seasons, to years, decades, and multiple decades. Understanding the wind resource on-site is crucial in determining the amount of electricity that is likely to be generated by a wind turbine and its temporal variability relative to demand.

Wind speed is a particularly significant variable in determining the amount of electricity a wind turbine can generate; the electricity generated is proportional to the cube of the wind speed, that is, doubling the wind speed results in eight times as much electricity being generated. This is further reason to determine the variability in wind resource, which will be looked at in detail below.

It is important to note that the region has had a successful wind farm in operation for over twenty years, since 2001. The Albany Grasmere Wind Farm is situated around 12 km south-west of Albany in an elevated coastal position; it is an onshore wind farm containing 18 turbines with a maximum generating capacity of 35.4 MW. This lends confidence that the coastal wind resource in the region is suitable for commercial exploitation.

Mean Wind Speed

The mean wind speed on-site is 7.62 m/s. This is a high mean wind speed as per Geoscience Australia as it is greater than 7.5 m/s [21].

Annual Variability

Figure 6-4 illustrates annual mean wind speeds for the period 2001 – 2020 inclusive at Discovery Bay. The annual mean wind speeds range from a maximum of 8.15 m/s in 2007 to a minimum of 7.03 m/s in 2003, which represents a 7% variation. The mean wind speed over the whole period of 7.62 m/s is included for comparison. As electricity generated by wind turbines is proportional to the wind speed cubed, variability in annual wind energy yield will be significantly greater than 7%: a 500kW wind turbine modelled under these conditions saw a ~26% variation in energy yield.

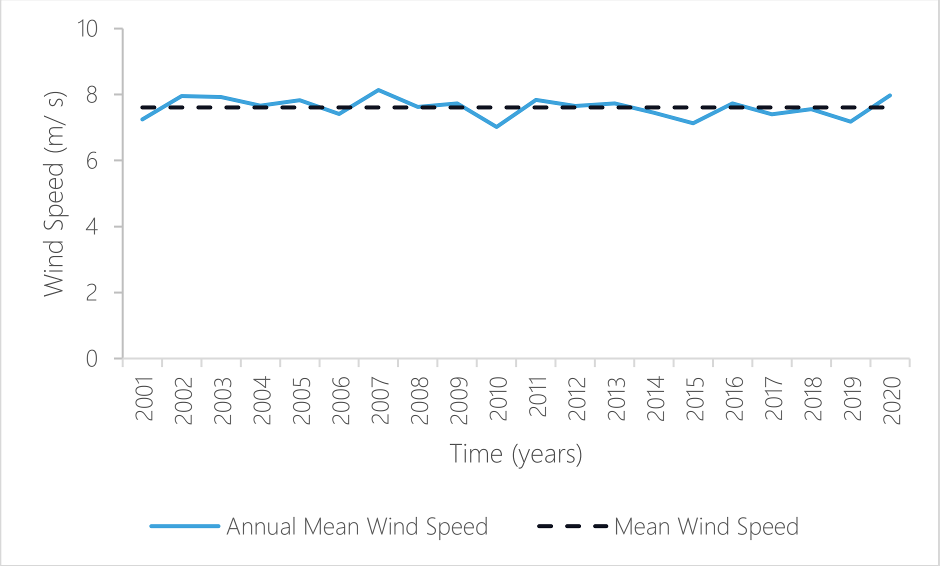


Figure 6-4. Annual mean wind speeds at Discovery Bay, 2001-2020.

Monthly Variability

Figure 6-5 shows the monthly mean wind speeds at Discovery Bay for the period 2001-2020 inclusive. The monthly mean wind speed ranges from a maximum of 8.57 m/s in July to a minimum of 6.84 m/s in April. The mean wind speed of 7.62 m/s is included for comparison. The range of monthly mean wind speeds represents a 12% variation and a 500kW wind turbine modelled under these conditions saw a ~34% variation in energy yield.

The four-month period of June to September contains the four greatest monthly mean wind speeds, ranging between 8.36 m/s to 8.57 m/s. The remaining months see monthly mean wind speeds closer to 7 m/s.

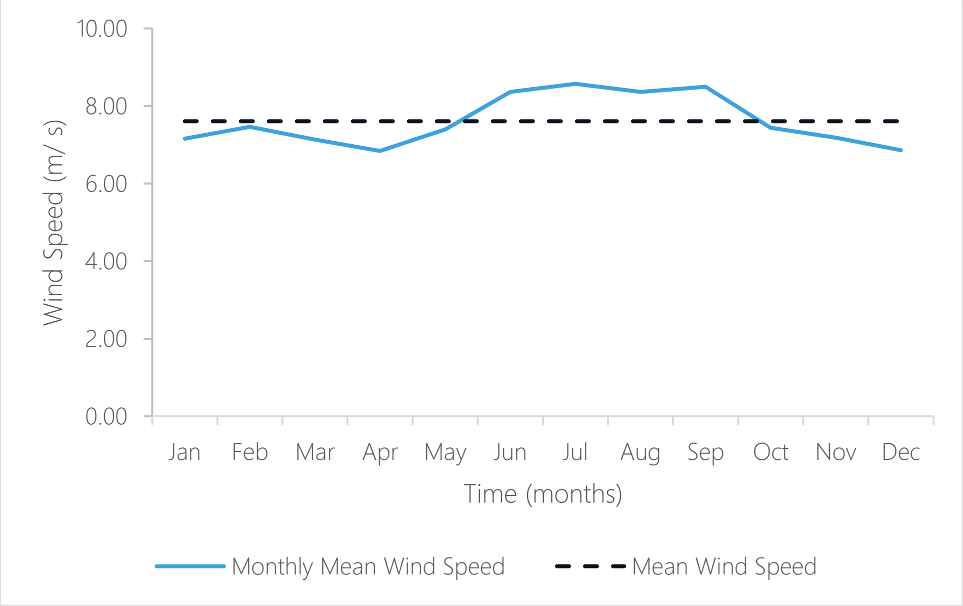


Figure 6-5. Monthly mean wind speeds at Discovery Bay, 2001-2020.

Hourly Variability

Analysis of hourly mean wind speeds at Discovery Bay shows two distinct daily wind patterns, illustrated in Figure 6-6. The period May to September typically sees higher, steady wind speeds overnight before a daily peak between 1000hrs and 1200hrs; the afternoon then brings the day's lowest wind speeds, decreasing from 1100hrs to a low at 1600hrs, before increasing steadily through the evening. In contrast, the period October to May typically sees its lowest wind speeds overnight with afternoon bringing steadily increasing wind speeds until a peak at 1700hrs.

The months of May-September see a daily peak of 8.48 m/s at 1100hrs. The hourly mean wind speed then steadily decreases to a daily low of 7.88 m/s at 1600hrs. A gradual increase in hourly mean wind speed then occurs to around 8.30 m/s at 2300hrs. The range of monthly mean wind speeds represents a 7% variation; a 500kW wind turbine modelled under these conditions saw a 12% variation in energy yield.

During the period October to April the hours between midnight and 1100 contain hourly mean wind speed from approximately 6.80 to 7.00 m/s. Afternoon brings an increase in hourly mean wind speed from 6.90 m/s at 1200 to 7.93 m/s at 1700hrs. This peak hourly mean wind speed then decreases steadily to 7.09 m/s at 2300hrs. The range of monthly mean wind speeds represents a 15% variation and a 500kW wind turbine modelled under these conditions saw a 24% variation in energy yield.

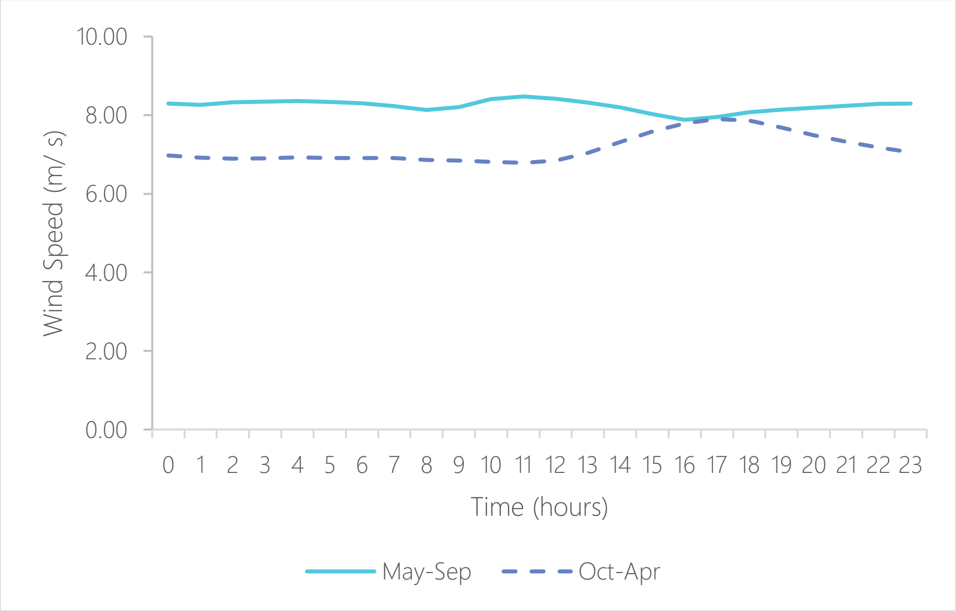


Figure 6-6. Hourly mean wind speeds at Discovery Bay, 2001-2020.

Assessment of Wind Resource

The wind resource assessed at the proposed project site offers a high mean wind speed across hourly, monthly, and annual timescales, based on 20 years of data.

The proposed project site has a mean wind speed of 7.62 m/s; which is categorised as high mean wind speed as per Geoscience Australia. Maximum and minimum mean wind speeds are between 6% and 13% greater than 7.5 m/s across annual, monthly, and hourly mean wind speeds while minimum mean wind speeds remain within 7% of this threshold. Table 6-5 summarises this wind resource assessment data.

Table 6-5. Summary of mean wind speed data.

	MEAN (m/s)	MAX. MEAN (m/s)	MIN. MEAN (m/s)	RANGE (m/s)
ANNUALLY	7.62	8.15	7.03	1.12
MONTHLY	7.62	8.57	6.84	1.73
HOURLY (MAY – SEP)	8.24	8.48	7.88	0.6
HOURLY (OCT – APR)	7.18	7.93	6.80	1.13

The variation of mean wind speed and how this can be complemented by other renewable resources will be explored in more detail in the Assessment of Solar Resource section.

6.3.3 Wave Resource

A wave is defined as a transfer of energy through the water, causing it to move in circular or orbital motion – essentially an energy movement, rather than water movement. Four main variables are responsible for generation of ocean waves: wind generation, lunar and solar gravitational fields causing large waves and tides, seismic disturbances that cause tsunamis and disturbances induced by bodies moving near or on the surface, such as ships [22].

In this study at King George Sound, only regular waves are being considered, whose energy resource can be considered a condensed form of wind energy. Unlike in wind, turbine technology cannot readily harness their energy which has given rise to a diversity of wave energy technology concepts. The main concepts today use turbines in water funnels or for displaced air and hydraulic power take-off in joints or mooring lines – but this can be implemented in devices of vastly different engineering design and ocean climates. The consistency and predictability of regular waves make this form of offshore ocean energy an innovative source of baseload energy.

The Southern Ocean off the Albany coast has a power density unparalleled internationally, with a high directional consistency. The primary wave energy development site for full-sized systems in the open ocean was identified as offshore the Albany Windfarm at Moodrenup/Sandpatch, where there is a grid connection to the Southwest Interconnected System (SWIS). As part of MERA research, a Datawell waverider buoy has been deployed 1.2 kilometres offshore from turbine 10 in approximately 30 metre water depth since July 2018. Real-time and archival data is available via wawaves.org. MERA researchers established the quality of this this wave energy resource in academic publications: e.g., this link.

For the purpose of this study, the secondary wave energy development site in Albany's natural deep-water outer harbour, King George Sound has been chosen for purposes of demonstration. While not ideal from a wave energy generation perspective, it provides a balanced outcome as a demonstration site as deployment is pragmatic and operation cost effective.

As part of MERA's M4 wave energy demonstration project, a Spotter waverider buoy has been deployed in approximately 13 metres water depth, 2.5 kilometres offshore Albany's Historic Whaling Station since December 2020, with data also available from wawaves.org .This site only experiences consistent surface waves during the summer months (October to March) and is much less energetic that the oceanic site. The reduced scale M4 energy converter, scheduled to be deployed at this site in late 2023, will not feed electricity to shore, however all data will be collected and used to validate models on device performance and power take-off and results will be published in academic journals. The data will also be used as an early input to the Marketplace demonstrations. The current performance predictions of the reduced scale M4 device were adopted in the electricity data used in this study, as described below.

Field measurements have been conducted to quantify the wave energy resource in the Albany region, including King George Sound. These studies have been led predominantly by MERA at the University of Western Australia. Measurements were obtained at two locations within the King George Sound. A Spotter wave data collection campaign was carried out between 29/12/2020 and 29/12/2021, while an Acoustic Wave and Current Profiler (AWAC) wave data collection campaign was carried out between 1/1/2017 and 31/12/2021 – ensuring seasonal variability will be included within the time series. Details of the two measurement campaigns are summarised in Table 6-6.

Table 6-6. Summary of two wave measurement campaigns.

	SPOTTER	AWAC
Latitude	35° 4′ 47.22′′ S	35° 2′ 4.8′′ S
Longitude	117° 58′ 44.88′′ E	117° 55′ 49.8′′ E
Water depth	12 m	13 m
Time range	29/12/2020 - 29/12/2021	1/1/2017 - 31/12/2021

Monthly Variability

Mean monthly significant wave height, wave period and wave power level across 2021, measured using the Spotter device located in the region of King George Sound offshore Albany, are illustrated in Figure 6-7., Figure 6-8 and Figure 6-9. These measurements show good correlation with measurements from an Acoustic Wave and Current Profiler (AWAC) at the location of Beacon 4, approximately 10 km of the spotter. The average period is 5.4s. The peak period can sometimes exceed 20s. In general, larger wave heights are exhibited in the summer months, resulting in higher wave power levels. The wave direction (i.e., the direction the waves are coming from, measured clockwise from north) is around 85°. The wave climate is a mix of (i) locally generated wind sea, and (ii) swell arriving from distant storms. Wind sea is more dominant in the summer and swell is stronger in the winter.

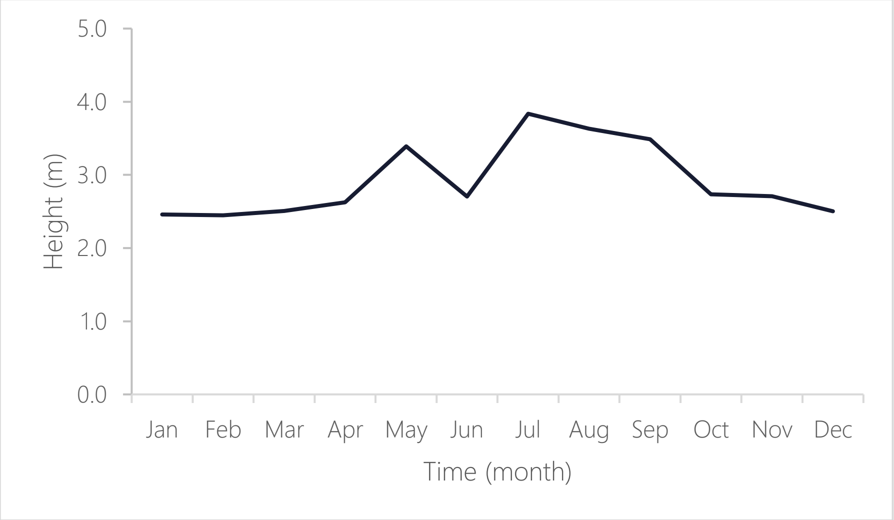


Figure 6-7. Monthly mean significant wave height.

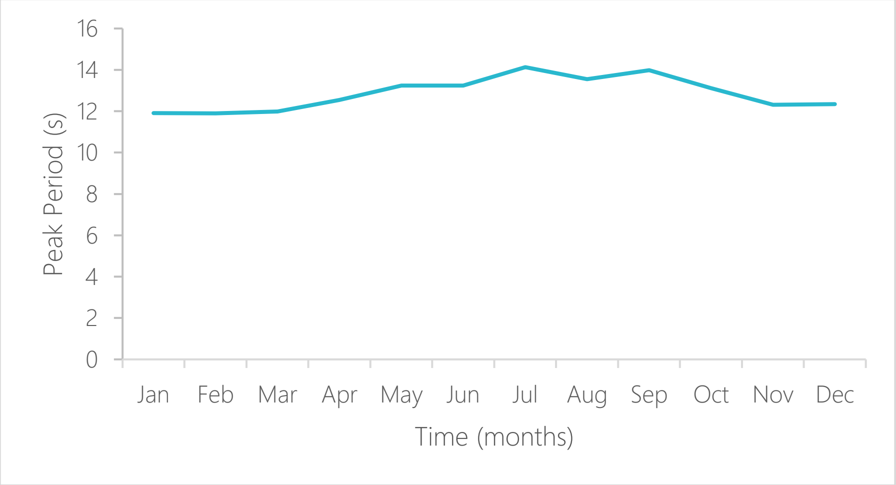


Figure 6-8. Monthly mean peak period.

The data shows that wave power is more prominent in winter months, around July, August, and September, and tails off in summer. This seasonal variability is significant, winter power is more than double that in summer.

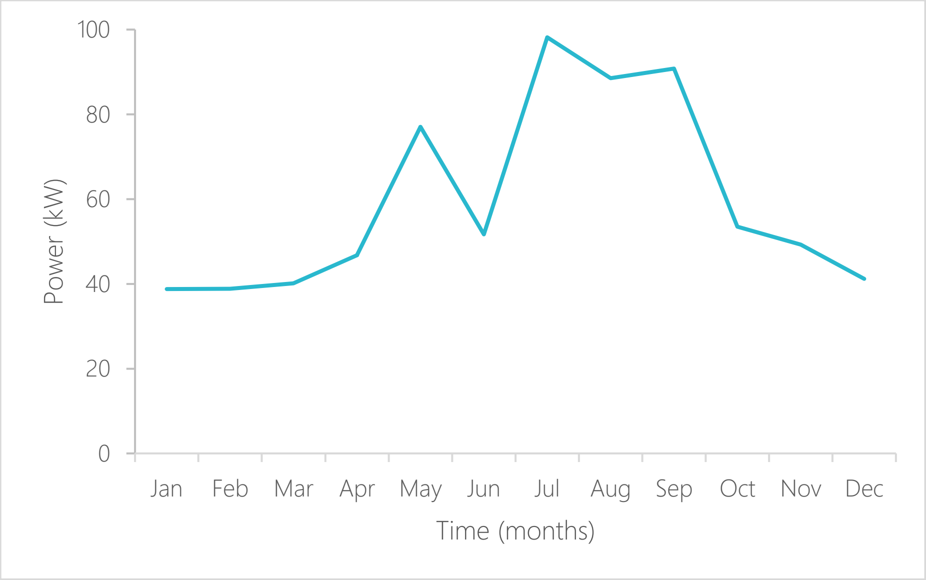


Figure 6-9. Monthly mean wave power level.

Figure 6-10 provides the percentage of occurrence of significant wave height and mean period, measured by the spotter.

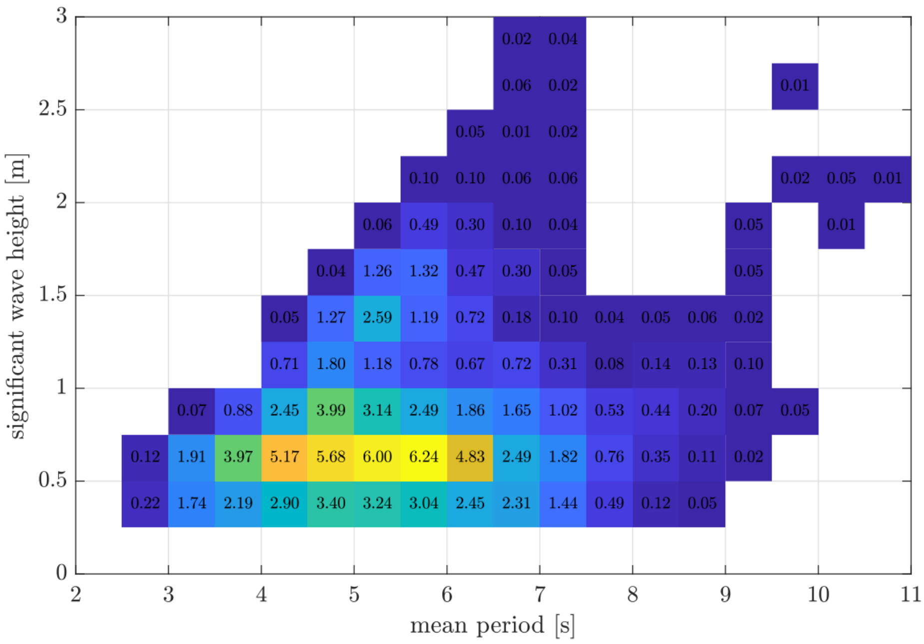


Figure 6-10. Percentage of occurrence of significant wave height and mean period. Measurements obtained using the Spotter [23].

6.3.4 Tidal Stream Resource

Tidal stream turbines extract energy from tidal flows. They work under the same principles as wind turbines, but using sea water as the working fluid, instead of air. The tidal stream generates a lift force on the rotor blade, causing rotation. This rotation drives a generator to produce electricity that can be exported to shore. Tidal stream energy is not being considered here as a potential power supply option for Discovery Bay due to the reason below.

Based on findings from publicly available data, the tidal stream energy resource in the Albany region is understood to be relatively un-energetic, preventing tidal stream turbine(s) from being a viable option to supply electricity. This conclusion is based on the following findings:

Site measurements of current speed conducted by the University of Western Australia within King George Sound at the location of Beacon 4. The measurements show that current speeds never exceed 0.6 m/s. For context, tidal stream turbines typically start generating power at current speeds exceeding 1 m/s [23].

Publicly available datasets obtained from global scale tidal stream models such as the Windy online application [28] demonstrate that tidal velocities never exceed 0.1 m/s within Frenchman Bay, as seen in Figure 6-11. For comparison, tidal stream turbines under operation today typically have a cut in speed, which describes the tidal current speed required for the turbine to start generating power, of between 0.5 – 1 m/s.

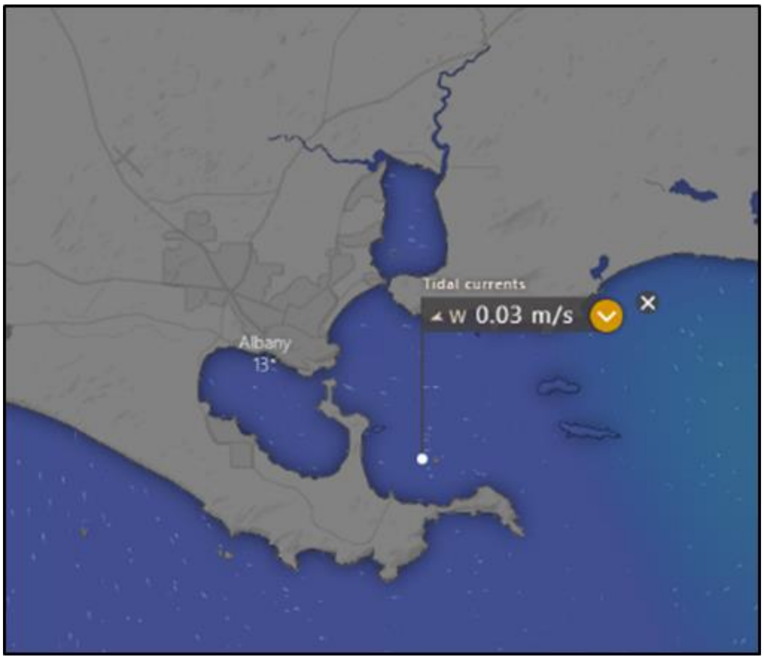


Figure 6-11. Current tidal speeds within King George Sound, from the Windy app.

Griffin D et al. (2021) have developed a hydrodynamic model of the shallow waters surrounding Australia [29]. Results from the model quantify the M2 (lunar) and S2 (solar) constituent amplitudes for tidal elevation and current speed. Results summarised in Table 6-7 shows that the M2 and S2 amplitudes of tidal elevation and major axis velocity in the South West of Australia are two orders of magnitude lower than those at sites/regions with a known tidal stream energy resource, such as Bass Strait and Tasmania, and the Arnhem located close to the Kimberley.

Table 6-7. *Comparison of tidal elevation and major axis velocity amplitudes between regions.*

REGION	TIDAL ELEVATION AMPLITUDE		MAJOR AXIS VELOCITY AMPLITUDE	
	M2	S2	M2	S2
South West	7	7	0.33	0.4
Bass	57	12	66	10
Tasmania	47	7	64	9
Arnhem	112	50	70	33

6.3.5 Comparison of Renewable Resources

It is useful to compare solar, wave and wind resources over time to assess their unique variabilities in complementing one another, or otherwise. A robust comparison is ensured by modelling electricity output from identical installed capacities of solar, wave and wind energy devices. Identical capacities of 100 kW are used. Findings are presented in the following sections: Seasonal Variability, Monthly Variability and Hourly Variability.

Seasonal Variability

Figure 6-12 illustrates the mean seasonal variability in electricity generation of solar, wave and wind energy devices. Predictably, peak solar electricity generation occurs during spring and summer while autumn and winter see lower levels of output.

Wave energy generates similar levels of electricity as solar during spring and summer but importantly increases generation during autumn and winter; this counterbalances the reduction in output from solar.

Wind energy provides greater output of generation per kW installed throughout the year compared to solar and wave energy, Wind energy plays a crucial role in winter by generating at its peak, which is counteracting the decrease in solar energy output during the same season.

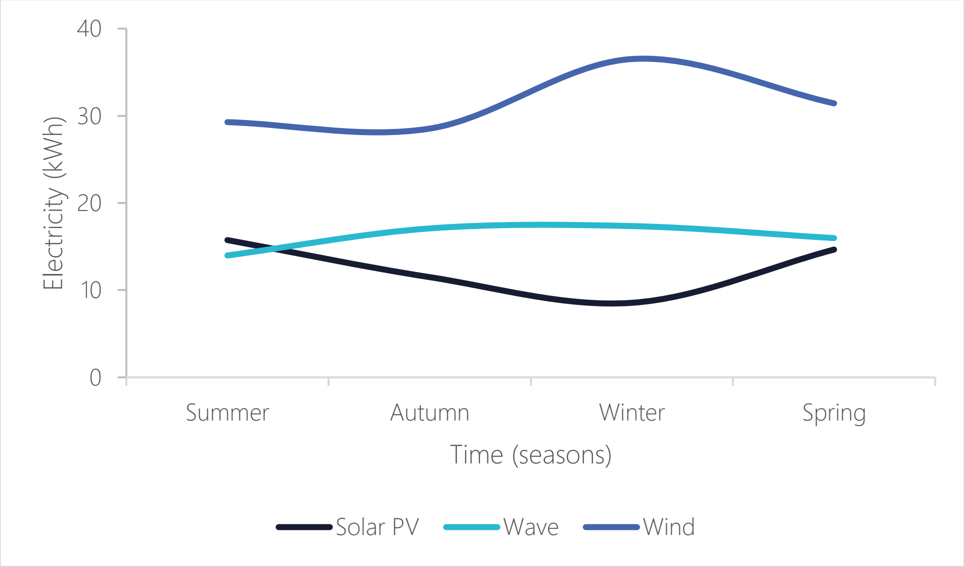


Figure 6-12. Seasonal variability of renewable resource at project site.

Monthly Variability

Figure 6-13 illustrates the monthly variability in electricity generation of solar, wave and wind energy devices, which provides greater temporal resolution to trends noted in the Seasonal Variability analysis.

Solar PV generates its peak output across the months of December and January, whilst generating lowest level of electricity during July.

Wave energy provides a generally greater electricity output than solar per kW of installed capacity; however, it is observed to have greater variation month to month. The electricity output for wave energy is greatest in the months of May and August, which counterbalances some of the output decline from the solar during these months.

Wind energy contributes the greatest electricity generation across all months. Output is greater during winter months. Output reaches its peak in July and troughs during summer months.

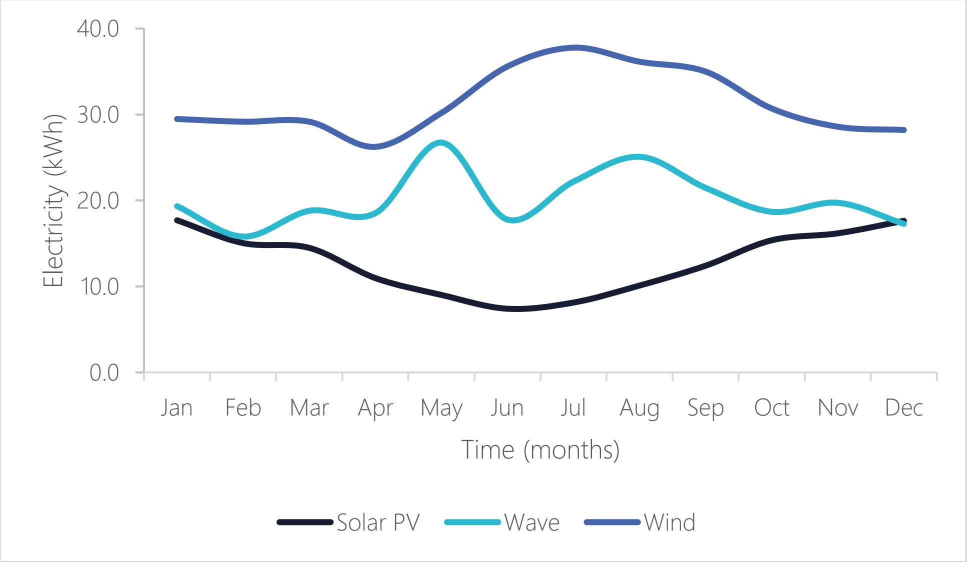


Figure 6-13. Monthly variability in renewable resource at project site.

Hourly Variability

Two months have been selected to compare the variability in electricity generation between wave, solar and wind energy over a 24-hour period. January and July were chosen to represent typical summer and winter months to compare further variability for different seasons.

Figure 6-14 illustrates the 24-hour variability in electricity generation of solar, wave and wind energy devices for the month of January. Predictably, solar electricity generation performs well during this summer month but is restricted to daylight hours. Wave and wind provide lower levels of electricity generation but over the entire 24 hours. Wind further complements solar by increasing its generation from 1200-1800hrs when solar begins to decrease generation in line with decreasing daylight.

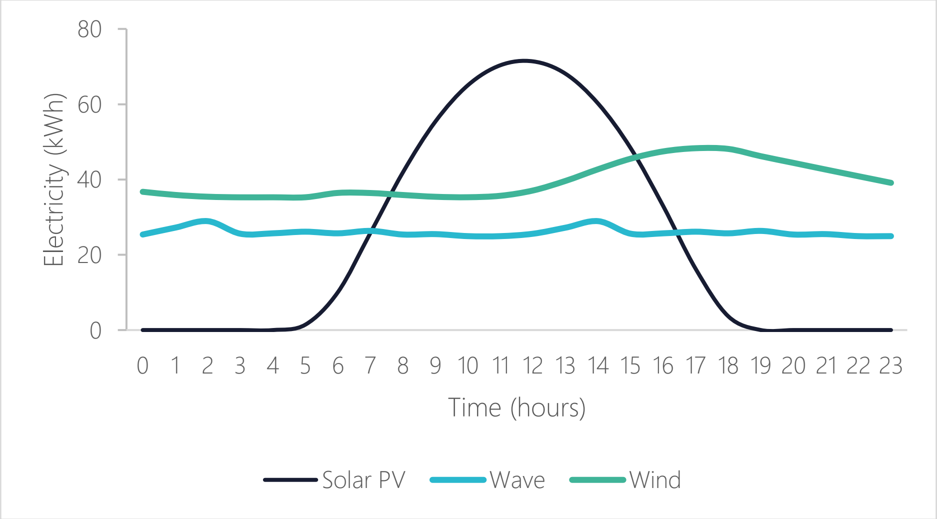


Figure 6-14. Hourly variability in renewable resource at project site, January.

Figure 6-15 illustrates the hourly variability in electricity generation of solar, wave and wind energy devices in July. Compared to January in Figure 6-14, solar provides significantly less electricity generation, peaking at ~41kWh compared to ~71kWh in January. Furthermore, solar is further restricted due to shorter days and therefore available generation hours over the 24-hour period. Wave energy generates across all hours but decreases slightly between 0800-1600hrs. Generation from wind energy is again the largest proportion of total generation, remaining fairly consistent across the day.

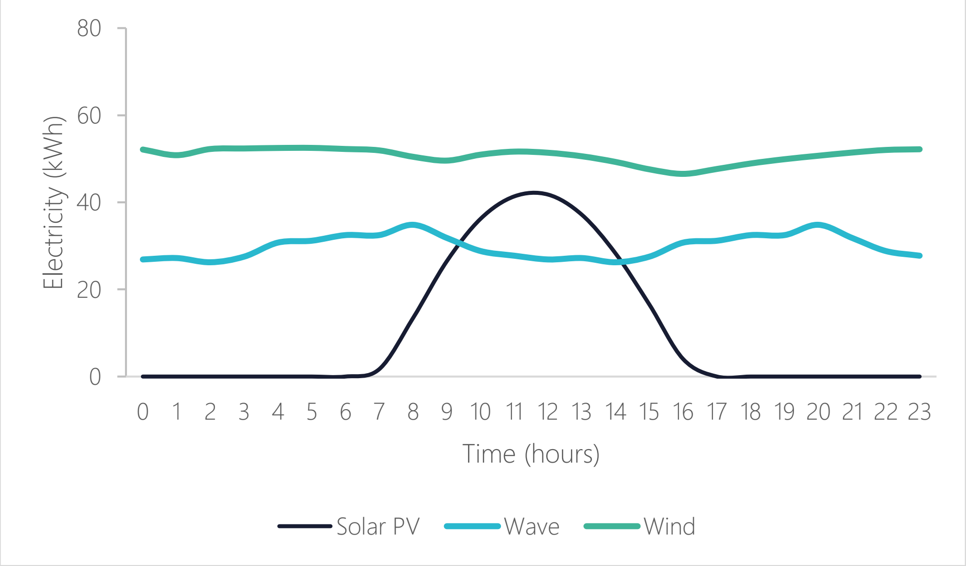


Figure 6-15. Hourly variability in renewable resource at project site, July.

6.3.6 Assessment of Renewable Supply Opportunity

Results from this resource assessment demonstrate that the relatively high solar, wind and wave resources in Albany warrant further consideration to supply Discovery Bay with renewable power. The tidal stream resource at the proposed project site is relatively unenergetic and as such is not worth pursuing further. Wind turbines demonstrate the greatest efficiency (also known as capacity factor) in producing energy per kW of installed capacity, followed by wave devices and then solar PV panels. This means that the installed capacity of wind turbines needed to produce a set amount of energy per year is lower than the installed capacity needed from solar PV and wave.

Results from the resource assessments also highlight elements of complementarity between the solar, wind and wave resources. At seasonal and monthly time scales, low solar resource during winter months is counterbalanced by high wind and wave resource. Similarly, low wind and wave resource during summer months are counterbalanced by high solar resource. At daily time scales the wind and wave resource can counterbalance the lack of nightly solar resource. This result highlights the benefits that can come from diversifying the mix of renewable power technologies that are used to meet demand. Utilising all three resources results in an energy mix that is likely to enhance balancing between supply and demand, resulting in a reduction in reliance on stored and/or reserve power, compared to cases that harness only one or two renewable resources.

The exact mix of solar PV, wind and wave capacity that maximises the performance of the energy system will also depend on the magnitude and temporal variability of demand. This is explored in the next section. Afterwards, the renewable resource and demand data are used as inputs to energy system modelling that investigates the mix of solar, wind and wave capacity that enhances balancing between supply and demand.

6.4 Electricity Demand Scenarios

6.4.1 Overview

Five scenarios have been created in alignment with AOEG to allow a variety of electricity supply and demand balances to be explored. Each scenario contains a unique combination of demand components, reflecting the distinct objectives of each scenario and allowing an understanding of how system design will have to change as electricity demand increases and becomes more complex. Table 6-8 provides a high-level description of each scenario and Table 6-9 provides more details by listing their respective electricity demanding components. The assumptions behind each component are then shown in Table 6-10.

Table 6-8. Overview of electricity demand scenarios.

SCENARIO	TITLE	DESCRIPTION	ANNUAL ELECTRICITY DEMAND [GWh]
1	*Early Deployment*	Quick deployment; small-scale generation; small-scale demand	0.24
2	*Base Case Deployment*	Expanded power demand to support additional on-site facilities	0.26
3	*The Wider Region*	Advanced power demand; introduction of large-scale desalination and H2 refuelling	3.13
4	*Discovery Bay Expansion*	Includes potential future development; excludes EV charging & H2	3.05
5	*All In*	All electricity demand components, including two hatchery sites and Eco-tourism resort	5.71

In respect of the EV charger, it is assumed that level 2 chargers are used with an intermediate power output. Level 2 refers to a dedicated AC EV charger typically installed in homes, apartment complexes, workplaces, shopping centres, hotels, etc. that have full charging times of 2 hours to 5 hours and 30 mins to 2 hours depending on the power output. This charging level is most suitable for anywhere the EV will be parked for a while. It is capable topping up the average daily use of a vehicle relatively quickly or deliver a full recharge overnight.

Water Filtration and Purification refers to a floor-standing water dispensing unit connected to the water mains and using electricity to filtrate and dispense large amounts of still and sparkling, chilled and ambient water.

Desalination refers to the process of removing salt from seawater and it is assumed that to carry it out, 3.5 KWh/m^3 of water are required (without energy recovery devices). Small-scale desalination was specified as 0.042 m^3/hr and large-scale desalination as 92 m^3/hr (modelled on supplying town of Denmark).

Table 6-9. All scenarios - components of electricity demand.

COMPONENTS OF DEMAND	1. EARLY DEPLOYMENT	2. BASE CASE DEPLOYMENT	3. THE WIDER REGION	4. DISCOVERY BAY EXPANSION	5. ALL IN
Phone chargers	✓	✓	✓		✓
E-Bike Charger	✓	✓	✓		✓
EV Charger	✓	✓	✓		✓
Water Filtration & Purification	✓	✓	✓	✓	✓
Desalination, small-scale		✓			
Desalination, large-scale			✓	✓	✓
Hydrogen Refueller			✓		✓
Remote Sensing					
Land - visual	✓	✓	✓	✓	✓
Marine audio & visual	✓	✓	✓	✓	✓
Facility Power					
Amphitheatre		✓	✓	✓	✓
Offices		✓	✓	✓	✓
Interactive/ Control Room		✓	✓	✓	✓
Staging Area		✓	✓	✓	✓
Potential Future Developments				✓	✓
Adjacent Businesses					
Hatchery					✓
Hatchery, Greenfields					✓
Eco-tourism Resort					✓

Table 6-10. Electricity demand - statement of assumptions.

COMPONENT	DESCRIPTION	INCLUDED IN SCENARIOS	ANNUAL ELECTRICITY DEMAND [MWh]
Desalination (large-scale)	Modelled on supplying town of Denmark	3-5	2821
Hatchery 2	Greenfields Hatchery, modelled as x4 current Hatchery demand	5	1318
Hatchery 1	Modelled as x2 current Hatchery demand	5	659
Eco-tourism Resort	Modelled after a 20-room traditional hotel.	5	487
Charger, EV	x1 Level 2 charging station for 3-4 vehicles	1, 2, 3, 5	137
Whaling Station, Museum & Cafe	Modelled using 2018 demand data	1-5	105
Hydrogen Refueller	x1 refueller for small vehicle	3, 5	55
Potential Future Developments	Assumes equivalent demand to x20 accommodation units	4	112
Lighting	External floodlighting	2-5	7
Control Room	For the Marketplace X4 laptops, x4 monitors, x1 large screen	2-5	3
Amphitheatre	Assumes 1000W system	2-5	2
Charger, E-Bike	Operating during opening hours	1, 2, 3, 5	2
Desalination (small-scale)	To supply water on-site	2	1
Offices	x2 offices (Discovery Bay, AOEG), each with x1 laptop and x1 monitor	2-5	1
Water Filtration & Purification	Mains fed drinking-water fountain	1-5	1
Staging Area	Floodlights	2-5	1
Remote Sensing, land	CCTV cameras	1-5	<0
Remote Sensing, marine	Camera and acoustic sensing	1-5	<0
Charger, phone	Public-facing phone chargers	1, 2, 3, 5	<0

6.4.2 Scenario 1 – Early Deployment

In this scenario, AOEG seeks to deploy an energy supply device as quickly as possible to raise awareness of the opportunities that ocean energy provides the region through demonstration.

Early deployment also provides opportunity to include virtual outputs from UWA's M4 wave energy converter, which will not have a physical cable connection to the land base. Instead, real time, virtual data can be transmitted by the M4 device, to a land-based demonstrator, where outputs can also be scaled to a full-size device. In this way the M4 can be modelled as a contributor to the renewable system, in combination with the outputs of wind and solar components, physically connected to a mini-microgrid.

On this basis of quick deployment, a smaller wave energy generation device is the likely supply source for connection, which limits the opportunity to meet for demand and will instead prioritise public demonstration. This scenario offers many opportunities for public-facing energy consumption such as charging of phones, bikes and cars and producing fresh water. All components are included in Scenario 1 are listed in Table 6-11.

Table 6-11. Scenario 1 - components of electricity demand.

COMPONENTS			
Cameras – land	Cameras – marine	Chargers – bike	Chargers – EV
Chargers – phone	Water filtration & purification	Whaling Station, Museum & Cafe	

Share of annual electricity demand by component is illustrated in Figure 6-16. The demand of the EV charger and the Whaling Station, Museum and Café account for 99% of the total electricity consumption in this scenario. The EV charger requires 137 MWh annually, or 56%, while the Whaling Station facilities account for 105 MWh, or 43% of the total demand. The remaining components account for 3 MWh, or 1%, combined.

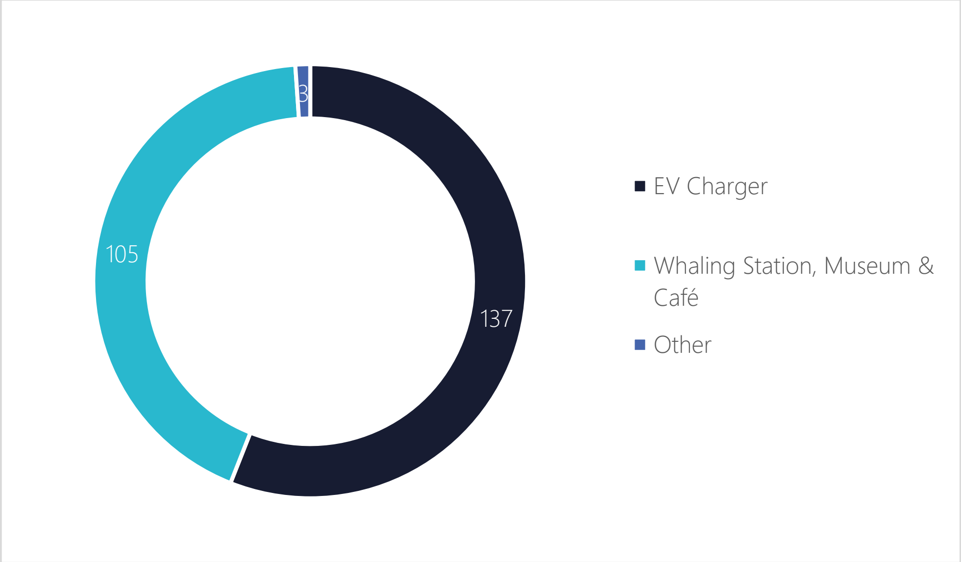


Figure 6-16. Scenario 1 - share of annual electricity demand by component (in MWh).

Hourly electricity demand across one day is illustrated in Figure 6-17. Daytime hours see the greatest demand, with peak demand between 0900hrs and 1600hrs as all components consume electricity. Electricity demand significantly reduces outside the Whaling Station, Museum and Café's opening hours; EV Charging is assumed to be restricted during this time.

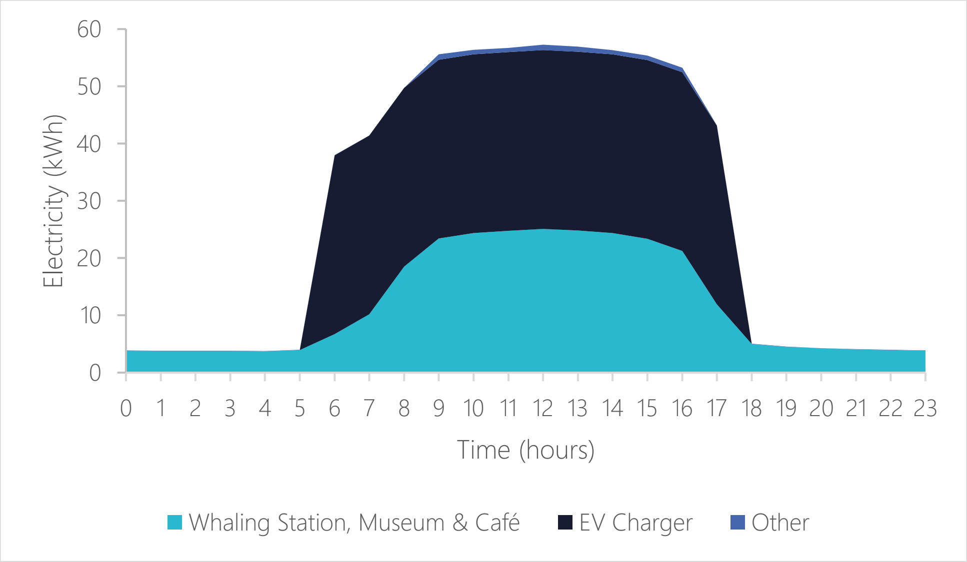


Figure 6-17. Scenario 1 - hourly electricity demand profile.

6.4.3 Scenario 2 – Base Case Deployment

This scenario considers including a number of relatively low-demand components at Discovery Bay, including: a refurbished amphitheatre, external security lighting, a control room for the Marketplace, a staging/ work area, two offices (one for Discovery Bay and one for AOEG) and small-scale desalination equipment. These additions provide an opportunity to benefit the site while only increasing annual electricity demand by ~6% as compared to Scenario 1. All components included in Scenario 2 are listed in Table 6-12.

Table 6-12. Scenario 2 - components of electricity demand.

COMPONENTS				
Amphitheatre	Cameras – land	Cameras - marine	Chargers – bike	Chargers – EV
Chargers - phone	Control Room	Desal. small	Lighting	Offices
Staging area	Water filtration & purification	Whaling Station, Museum & Cafe		

The share of annual electricity demand by component is illustrated in Figure 6-18. Similar to Scenario 1, EV charging and the Whaling Station facilities comprise the majority of demand, however, components combined in the 'other' category now share 7% of total demand, or 17 MWh.

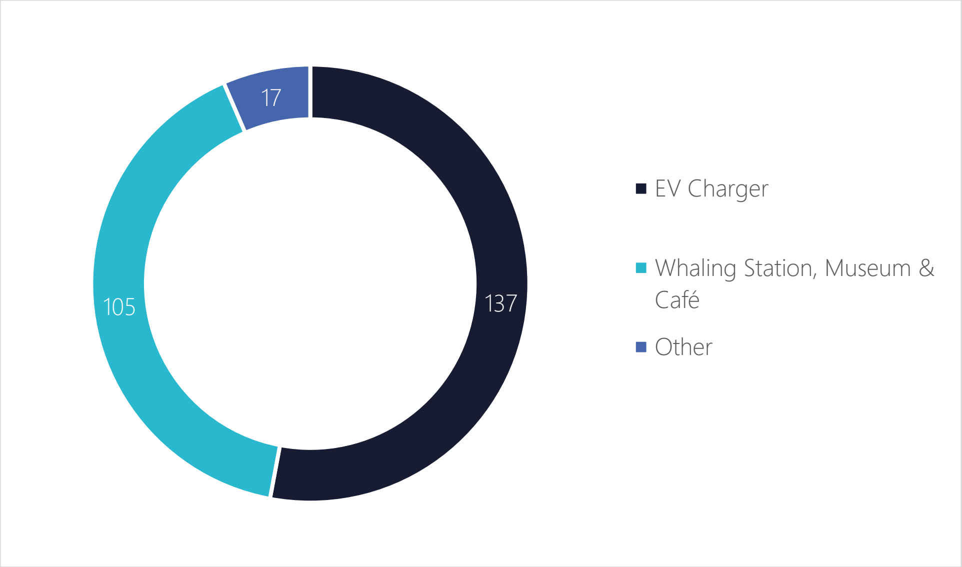


Figure 6-18. Scenario 2 - share of annual electricity demand by component (in MWh).

Hourly electricity demand across one day is illustrated in Figure 6-19. Similar to Scenario 1, daytime hours see the greatest demand and peak demand is between 0900hrs and 1600hrs; electricity demand significantly reduces outside the Whaling Station, Museum and Café's opening hours. The electricity demand of components in the 'other' category is greater than in Scenario 1, across all hours. The offices, control room and staging area increase demand during the day while the amphitheatre and lighting consume electricity in the evening and overnight. Small-scale desalination demands electricity consistently each hour.

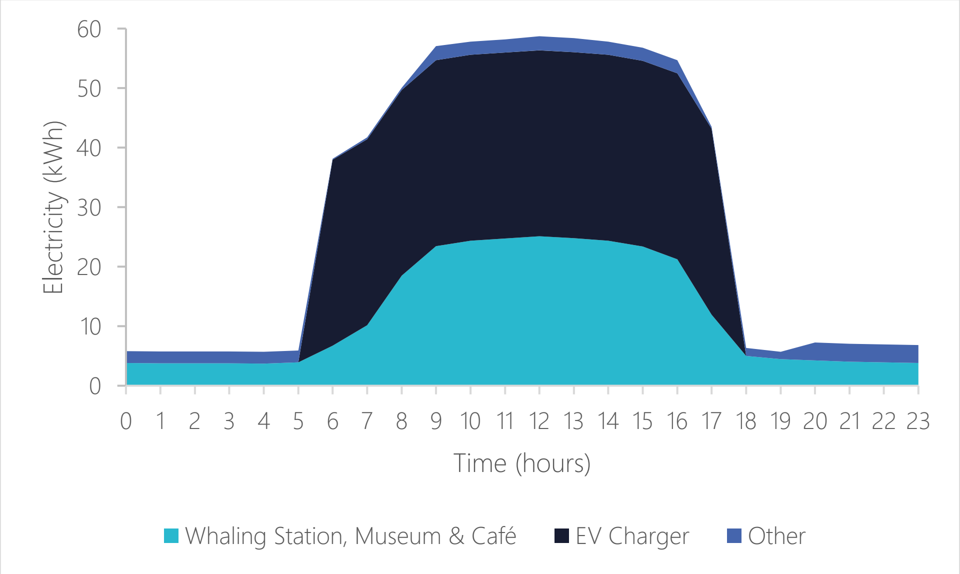


Figure 6-19. Scenario 2 - hourly electricity demand profile.

6.4.4 Scenario 3 – The Wider Region

Scenario 3 considers on-site electricity generation powering businesses in the wider region to Discovery Bay, as well as facilities at Discovery Bay. Desalination is also increased from small-scale to large-scale and hydrogen refuelling is introduced, while all other components noted in Scenario 2 remain constant (for both Discovery Bay and the Marketplace). This scenario marks a significant increase in annual electricity of ~350% when compared to Scenarios 1 and 2. All components included in Scenario 2 are listed in Table 6-13.

Table 6-13. Scenario 3 - components of electricity demand.

COMPONENTS				
Amphitheatre	Cameras – land	Cameras - marine	Chargers – bike	Chargers – EV
Chargers-phone	Control Room	Desal. large	H_2 refueler	Lighting
Offices	Staging area	Water filtration & purification	Whaling Station, Museum & Cafe	

Share of annual electricity demand by component is illustrated in Figure 6-20. Large-scale desalination accounts for 90% of total demand and is based on supplying a fresh water supply to the town of Denmark, which has a freshwater deficiency. Consequently, both EV Charging's and the Whaling Station, Museum and Café's share of are 5% and 3%. Components combined in the 'other' category, including H2 refuelling, demand 2% of total electricity consumption, or 70 MWh.

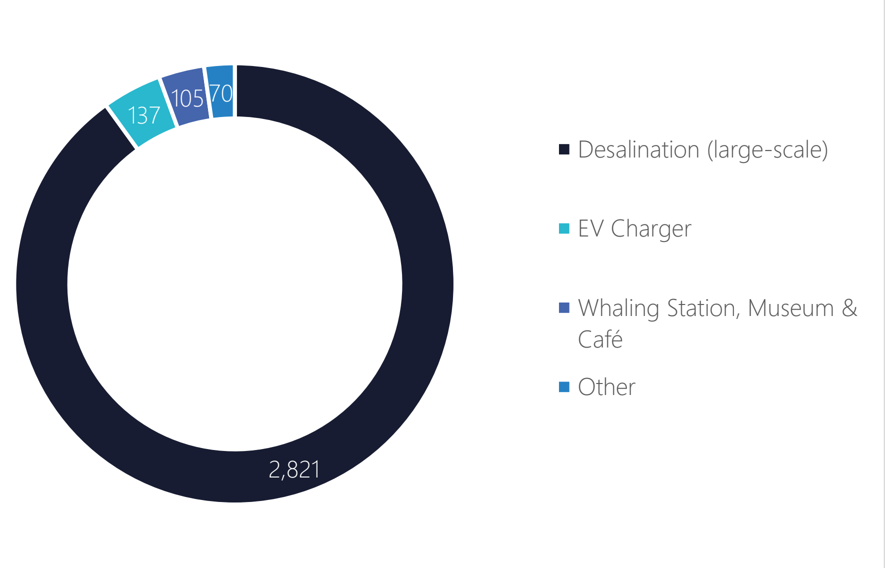


Figure 6-20. Scenario 3 - share of annual electricity demand by component (in MWh).

Hourly electricity demand across a single day is illustrated in Figure 6-21 and Figure 6-22. Large-scale desalination's electricity demand has been illustrated separately as it is consistently large and dilutes the impact of other demand components that vary throughout an average day., This hourly demand profile for Scenario 3 differs greatly to those in Scenarios 1 and 2; rather than electricity demand reducing significantly outside general business hours, Scenario 3 maintains a high demand across all 24 hours.

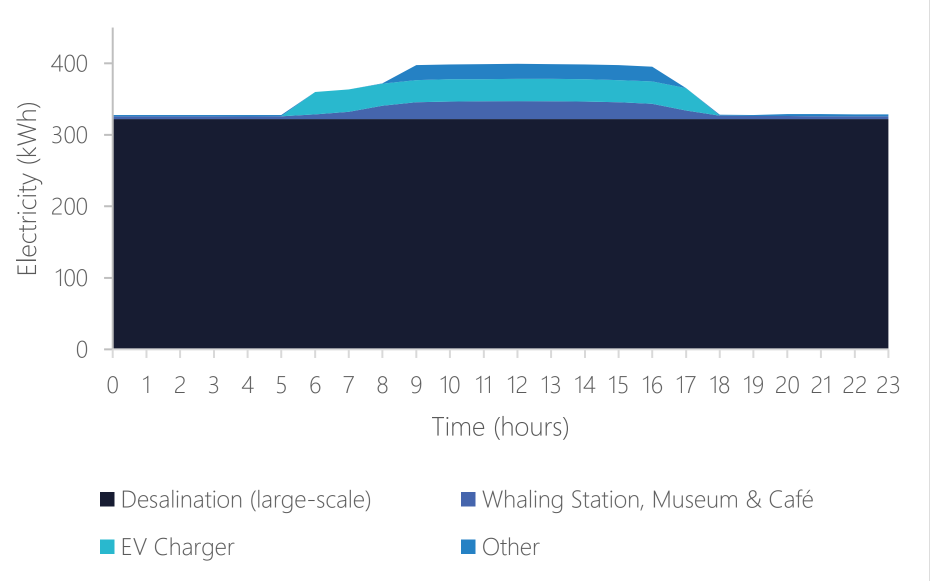


Figure 6-21. Scenario 3 – large-scale desalination hourly electricity demand profile.

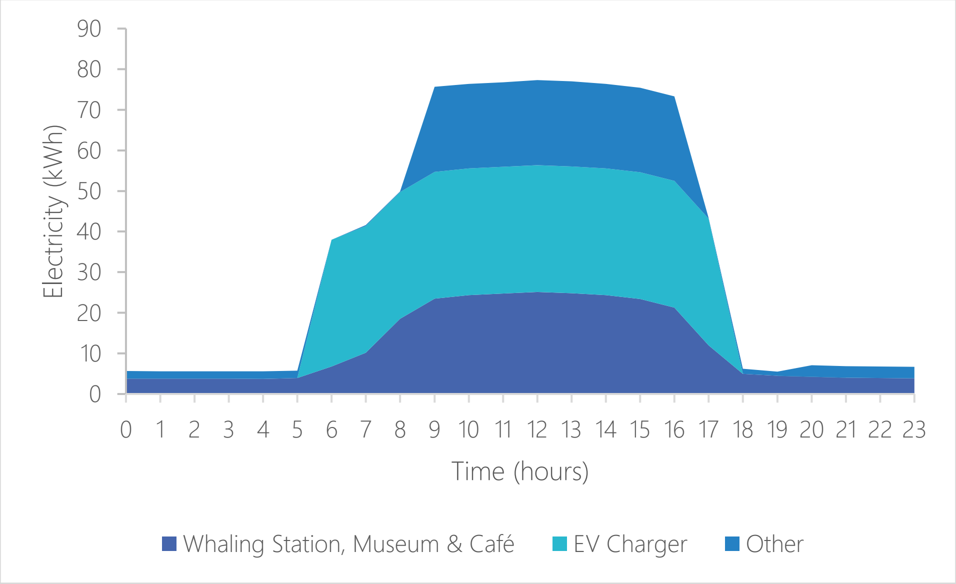


Figure 6-22. Scenario 3 - hourly electricity demand profile (excluding large-scale desalination).

6.4.5 Scenario 4 – Discovery Bay Expansion

Scenario 4 considers a further expansion of Discovery Bay's facilities (details which are confidential). All chargers and hydrogen refuelling are excluded from this scenario. Annual electricity demand remains broadly similar as compared to Scenario 3, decreasing by ~3%. All components included in Scenario 4 are listed in Table 6-14.

Table 6-14. Scenario 4 - components of electricity demand.

COMPONENTS					
Amphitheatre	Cameras – land	Cameras - marine	Control Room	Desal. large	DB. Expansion
Lighting	Offices	Staging area	Water filtration & purification	Whaling Station, Museum & Cafe	

Share of annual electricity demand, by component, is illustrated in Figure 6-23. Large-scale desalination accounts for 92% of demand while the additions of the potential future developments share 4% of total demand. The Whaling Station, Museum and Café's share is 3% while all other components, combined, account for only 1% of total demand.

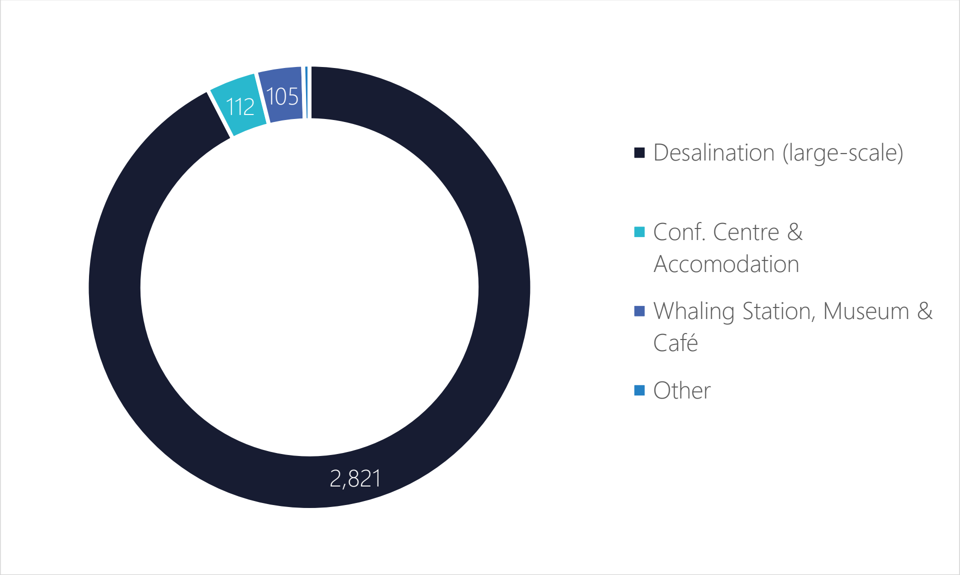


Figure 6-23. Scenario 4 - share of annual electricity demand by component (in MWh).

Hourly electricity demand across one day is illustrated in Figure 6-24 and Figure 6-25. Large-scale desalination's electricity demand has been illustrated separately as it is consistently large and dilutes the impact of other demand components that vary throughout an average day The daily demand profile for Scenario 4 is similar to the profile in Scenario 3, however even more uniform across all 24 hours of the day. This is largely due to the potential future developments requiring additional electricity outside of daylight hours.

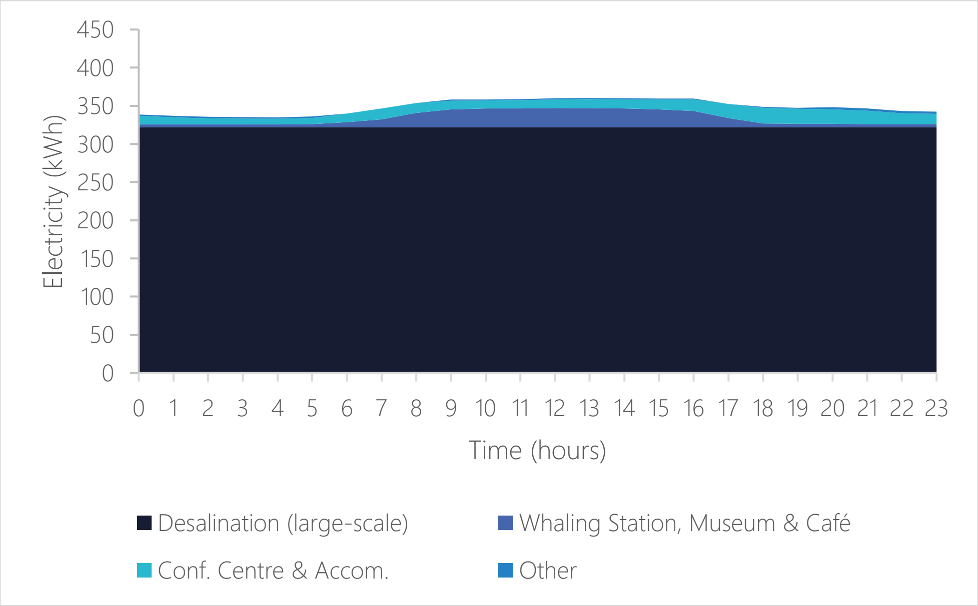


Figure 6-24. Scenario 4 – large-scale desalination hourly electricity demand profile.

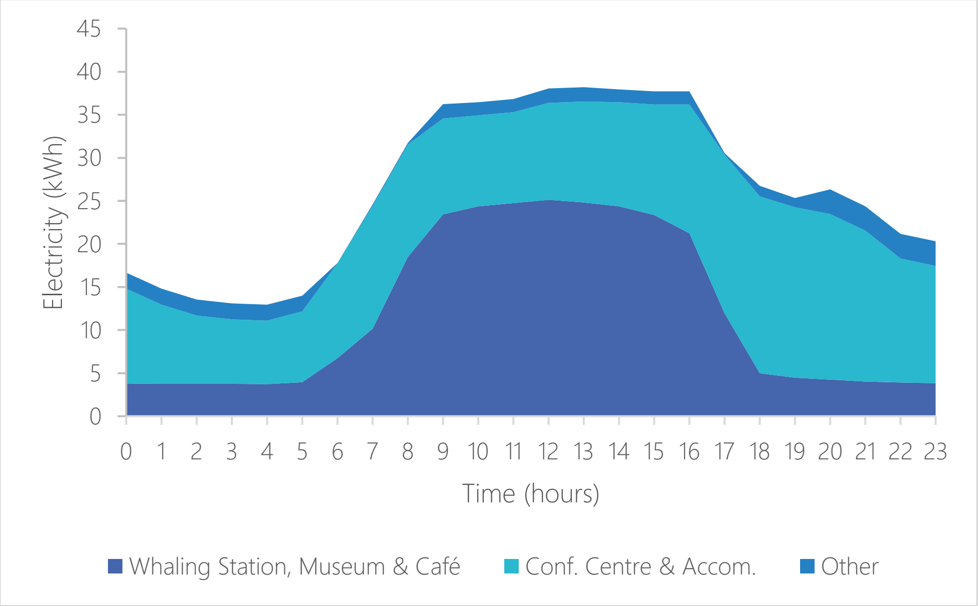


Figure 6-25. Scenario 4 - hourly electricity demand profile (excluding large-scale desalination).

6.4.6 Scenario 5 – All In

Scenario 5 considers all components noted in previous scenarios are included, as well as three adjacent businesses Eco-tourism Resort and two hatcheries. This scenario comprises the greatest electricity demand of all five scenarios. Electricity demand is ~80% to ~90% greater than in Scenarios 3 and 4. All components included in Scenario 5 are listed in Table 6-15.

Table 6-15. Scenario 5 - components of electricity demand.

COMPONENTS					
Amphitheatre	Cameras – land	Cameras - marine	Chargers – bike	Chargers – EV	Chargers - phone
Control Room	Desal. large	DB. Expansion	Eco Resort	Hatchery 1	Hatchery 2
H2 refueler	Lighting	Offices	Staging area	Water filtration & purification	Whaling Station, Museum & Cafe

The share of annual electricity demand, by component, is illustrated in Figure 6-26. Large-scale desalination and Hatchery 2 demand 75% of total annual electricity consumption in this scenario. Desalination accounts for 2.82 GWh, or 51% of total electricity demand. Hatchery 2 accounts for 1.32 GWh, or 24%, of total electricity demand. The remaining 25% of annual electricity demand is shared by: Hatchery 1 at 0.66 GWh or 12%; Eco Resort at 0.49 or 9%; all other components at 0.23 GWh or 4% of total annual electricity demand.

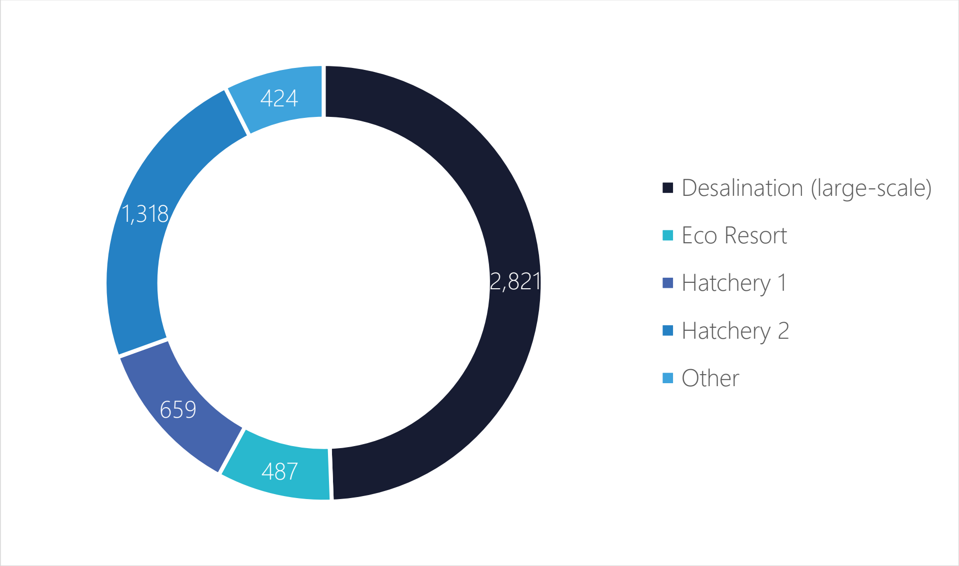


Figure 6-26. Scenario 5 - share of annual electricity demand by component (in MWh).

Hourly electricity demand across one day is illustrated in Figure 6-27Figure 6-27. Total demand sees two peak events at 0000hrs and 0900hrs. The 0000hrs peak is due to Hatchery 1 and Hatchery 2 increasing their demand at this time while the 0900hrs peak is due to the increase in consumption caused by facilities opening to the public. Overnight demand remains significant in this scenario.

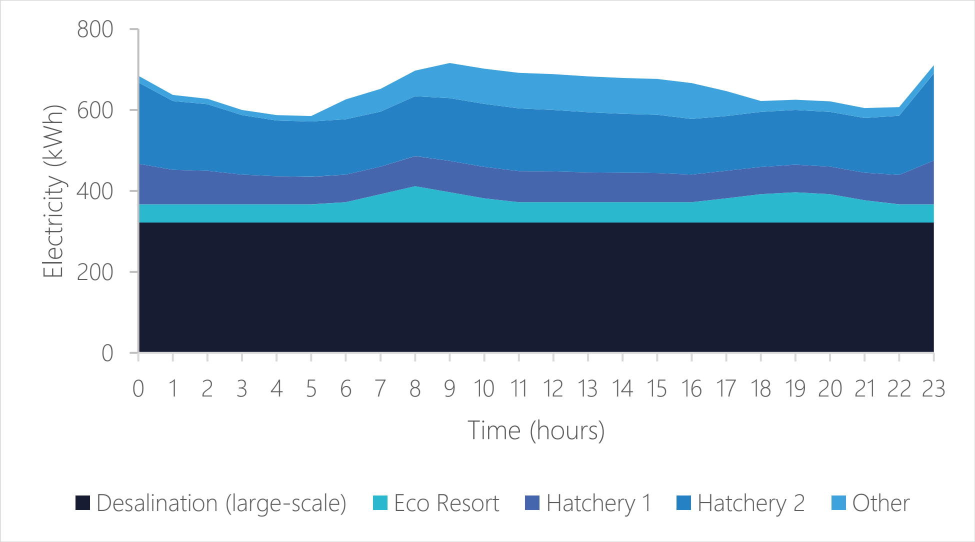


Figure 6-27. Scenario 5 - hourly electricity demand profile.

6.4.7 Comparison of Scenarios

Total Annual Electricity Demand

The annual electricity demand for each scenario is summarised in Figure 6-28. Where components that consume significant proportions of annual demand are highlighted, namely: large-scale desalination, the Eco-tourism Resort, Hatchery 1 and Hatchery 2. The total annual electricity demand of Scenario 5 is almost twice as large as Scenarios 3 and 4; Scenarios 3 and 4 are ~12 times larger than Scenarios 1 and 2. Large-scale desalination is a significant component of electricity demand in Scenarios 3-5. In addition, businesses adjacent to Discovery Bay also demand relatively large amounts of electricity annually.

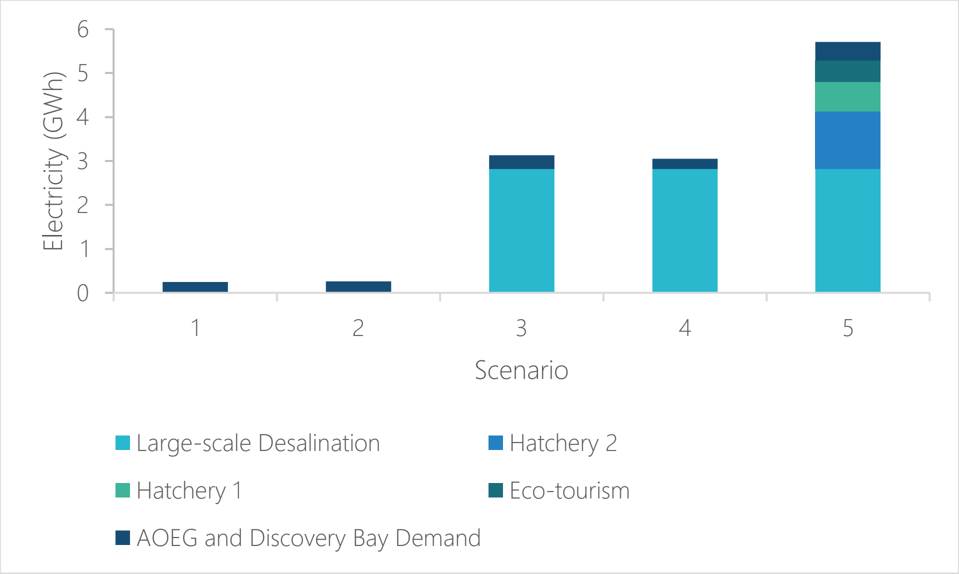


Figure 6-28. All scenarios – annual electricity demand with significant components highlighted.

Hourly Demand Profiles

Hourly electricity demand across one day, for all scenarios, is illustrated in Figure 6-29. Scenarios 1 and 2 share similar demand levels across the day; peak demand is during general business hours and demand drops outside this. Scenarios 3 and 4 consume similar amounts of electricity but Scenario 3 demonstrates a clear peak in electricity demand during business hours. The inclusion of EV charging in Scenario 3 and potential future developments in Scenario 4 accounts for this difference; EV charging occurs during business hours whereas the potential future developments see a more stable demand across the 24 hours. Scenario 5 demonstrates a distinct demand profile; demand from adjacent businesses sees overnight demand peak at 0000hrs with a second daily peak at 0900hrs as the public access demand components.

Broadly, Scenarios 1 and 2 require greatest electricity generation during the day while all other scenarios require electricity generation across all 24 hours. Significant evening and overnight electricity demand in Scenario 3 and 4 can be attributed to large-scale desalination. While large-scale desalination does contribute to Scenario 5's overnight demand, it is important to note that adjacent businesses, particularly the hatcheries, require significant electricity supply through the night.

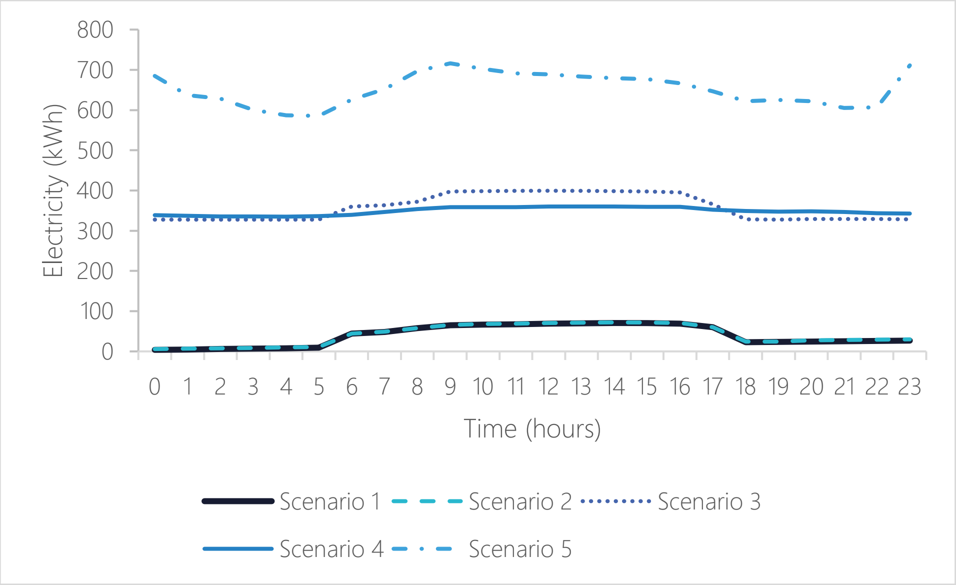


Figure 6-29. All scenarios – hourly electricity demand profile.

6.5 Energy System Modelling

Energy system modelling is implemented to simulate the hourly power flows between renewable and or grid power supply, with Discovery Bay electricity demand. The energy system model architecture is illustrated in Figure 6-30. Renewable power technologies such as solar PV, wind and wave provide the primary source of power supply to Discovery Bay for this modelling. A range of onshore and offshore renewable power technologies are considered. Renewable power supply is supported by energy storage, which helps absorb surplus renewable energy to use during periods when demand exceeds renewable generation.

Renewable power is curtailed when it cannot be used by the system to either meet demand, or be stored (i.e., when the battery is fully charged). Reserve power is used to balance demand during periods when demand cannot be met by renewable energy and or stored energy. The source of this reserve power is explored further in this report, but could come from the grid, or diesel generators for example.

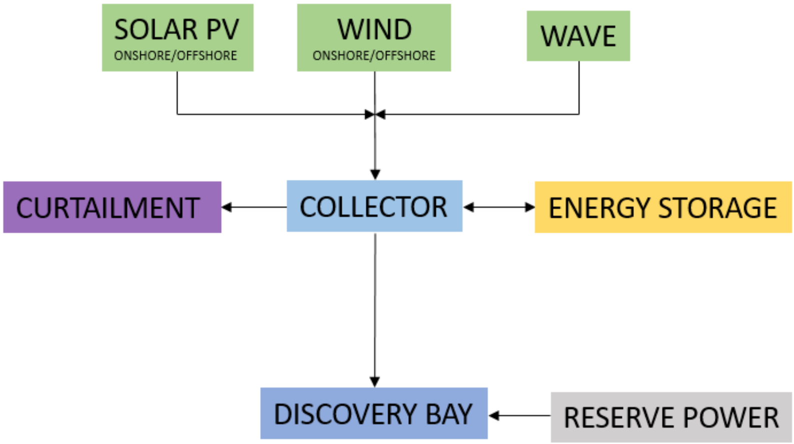
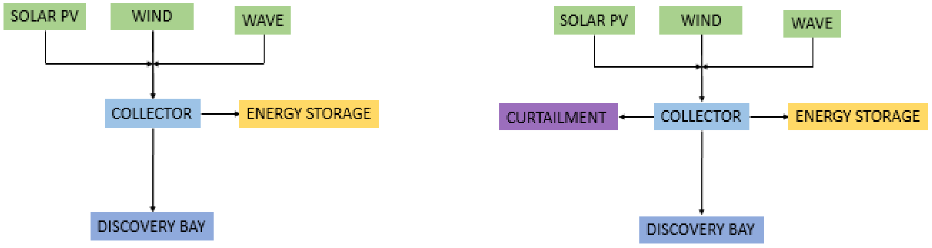


Figure 6-30. Energy system model schematic.

Figure 6-31 shows the different operating states of the energy system model in more detail. At times when renewable power exceeds demand, energy storage is adopted to help absorb surplus renewable power (Figure 6-31a). The stored energy can be used in future periods when demand exceeds renewable power. If the energy storage system is fully charged, any surplus renewable power is curtailed (Figure 6-31b). If the energy storage system becomes fully discharged, grid power is used for balancing (Figure 6-31c).

At times when demand exceeds renewable power, stored energy is used to balance demand (Figure 6-31d). At times when the stored energy cannot fully balance the demand, reserve power is also used Figure 6-31e). When the battery is fully discharged, reserve power becomes the sole source of supply (Figure 6-31f).

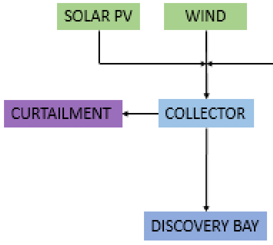
The energy system model simulates cases where the annual renewable energy generation is equal to annual demand, as well as cases where renewable energy generation exceeds demand by 50% (i.e. oversizing of renewables). The model is run with a range of energy storage specifications, as well as without energy storage at all.

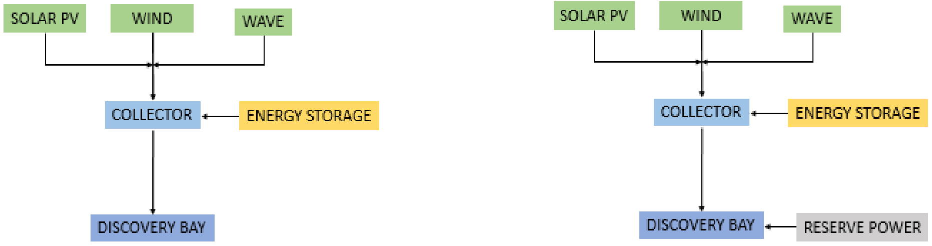


(a) Renewable power surplus < Available storage capacity

(b) Renewable power surplus > Available storage capacity

(c) Renewable power surplus > Available storage capacity,
energy storage fully charged





(d) Renewable power shortage < Available stored energy

(e) Renewable power shortage > Available stored energy

(f) Renewable power shortage > Available stored energy,
Energy storage fully discharged

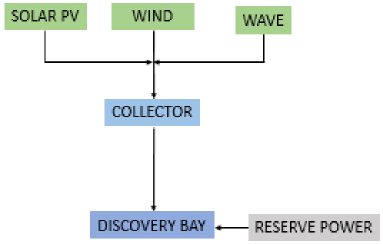


Figure 6-31. Energy system operating modes.

6.5.1 Input Data

Renewable resource data

The renewable power time series data is derived from climate re-analysis data. Climate reanalysis data is produced by assimilating historical weather observations into a modern numerical weather prediction model to produce a dataset of weather parameters. Table 6-16 details the climate reanalysis data used in assessing the solar, wave and wind resource at Discovery Bay.

Table 6-16. Data sources used in renewable resource assessment.

DATA	SOURCE	PERIOD	RESOLUTION
Solar Irradiance	The Satellite Application Facility on Climate Monitoring (CM SAF)	2001-2020	Hourly
Wave (significant wave height, peak period)	University of Western Australia	2018	Hourly
Wind Speed	NASA MERRA-2	2001-2020	Hourly

Equation 1 describes how to calculate solar PV power from solar irradiance;

Equation 1

$$P_s = GA_s\eta$$

where G is solar irradiance, A_s is the total area of the solar PV panels and η is the conversion efficiency of the solar PV panels.

Equation 2 describes how to calculate wind power from wind speed;

Equation 2

$$P_w = \frac{1}{2}\rho_w u_w^3 c_p A_w$$

where ρ_w is the density of air, u_w is the velocity of the inflow to the turbine rotor, c_p is the power coefficient of the wind turbine, and A_w is the swept area of the wind turbine.

Ocean waves transmit energy that can be extracted to generate electricity using wave energy converters installed offshore. Equation 3 describes available wave energy;

Equation 3

$$P_{wv} = \frac{\rho_{wv} g^2}{64\pi} H_s^2 T_e d$$

where $\rho_{wv}$is the density of seawater, g is acceleration due to gravity, H_s is significant wave height, T_e is the wave energy period, and d is the capture width of the device. Wave power was derived from the wave power matrix of a best-in-class, 750 kW wave energy device [24] . A wave power matrix provides the generated power of the device for any combination of significant wave height and wave period.

Estimating capital and operating costs associated to energy generation

Following the completion of the Renewable Resource Assessment (see Section 6.3), capital and operating cost profiles (in real terms 2022) were developed for the energy modelling scenarios selected as inputs to the Business Plan in Appendix B. The types of energy generation considered are onshore and offshore wind energy and solar photovoltaics (PV).

Cost estimations from a number of proposed installed capacity sizes were available from public research in distributed generation. These were used where possible (e.g. residential solar PV, onshore wind) rather than utility or large-scale cost guidance which tends to be the case for GenCosts estimates except for Rooftop Solar. The term distributed generation refers to small-to-medium power plants located at or near electricity users such as in off-grid or remote locations. In this context, distributed generation resources also include distributed generation technologies, located within the distribution system or on the customer side of the meter as it would be the case for the selected site [30].

Such capacity sizing resulted on the same ranking of technologies with respect to costs as seen in the draft GenCost 22-23 Global NZE post scenario (see Figure 6-32). Note that in the GenCost Wave study a decrease in CAPEX is plotted against cumulative installed capacity rather than time. Under current trends and the proposed timetable, the Marketplace would not benefit from CAPEX reduction due to cumulative construction of wave energy capacity.

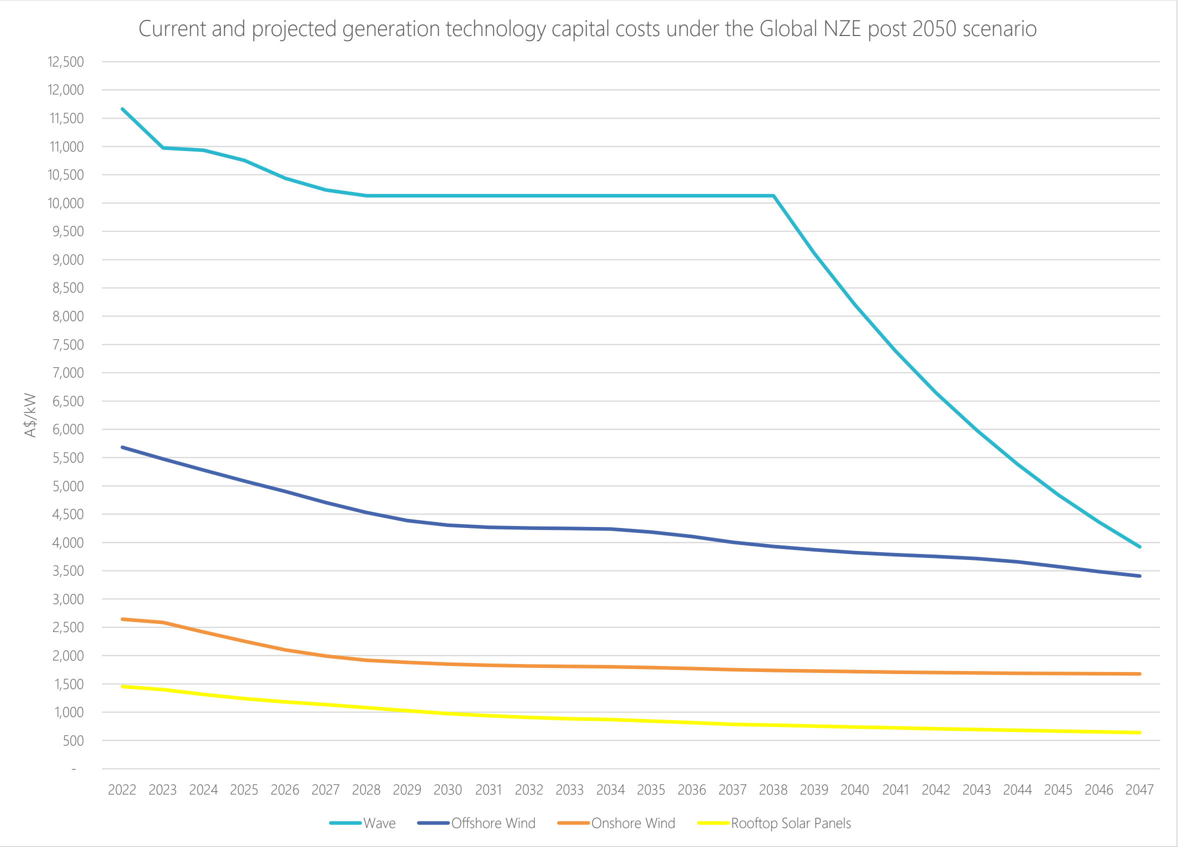


Figure 6-32. Current and projected generation technology capital costs under the Global NZE post scenario.

Having been provided with annual energy production figures expected for the Marketplace, LCOEs were calculated for each cost/resilience case and for each size of installed capacity in the Marketplace. These LCOEs and, in the case of the batteries, specific Levelised Cost of Storage (LCOS) guidance [31] were used as some of the inputs for the Energy System Modelling (see section 6.5). Table 6-17 summarises the different types of generation, their associated installed capacity sizes and calculations available.

Table 6-17. Summary of cost input assumptions and outputs developed and modelled during the study.

ENERGY GENERATION/ STORAGE	INSTALLED CAPACITY SIZES (KW)	CAPEX	OPEX	LCOE	LCOS
Onshore Solar PV	36, 48, 60, 150 300, 450, 500, 750	✓	✓	✓	
Floating Solar PV	36, 48, 60, 150 300, 450, 500, 750	✓	✓	✓	
Onshore Wind Turbine	12, 36, 48, 60 300, 450, 500, 600, 750, 1250	✓	✓	✓	
Offshore Wind Turbine – Fixed Bottom	12, 36, 48, 60 300, 450, 500, 600, 750, 1250	✓	✓	✓	
Offshore Wind Turbine – Floating	12, 36, 48, 60 300, 450, 500, 600, 750, 1250	✓	✓	✓	
Wave Energy	6, 10, 45, 55, 85, 125 300, 450, 700, 780, 1400	✓	✓	✓	
Lithium Ion Battery					✓
Vanadium Redox Flow Battery					✓

Onshore Solar Photovoltaic (PV)

The capital costs of A$1,333 per kilowatt [12] for rooftop solar panels generation technology in Australia were used for scenarios 3 to 5 where installed capacity was 300, 450, 500 and 750kW. Residential rooftop solar systems were used for smaller installed generation capacities such as the 36kW case. Smaller systems resulted in a higher costs on a per kilowatt basis (A$1,853/kW) [32]. A sliding scale was then applied between the two capex levels to derive capital costs for scenarios 1 to 2 (48, 60 and 150kW) – see Figure 6-33.

Contingencies and insurance of 20% and 1% were applied to the capital cost subtotal. It was assumed that 2% of total capex would be spent on annual operating costs (OPEX).

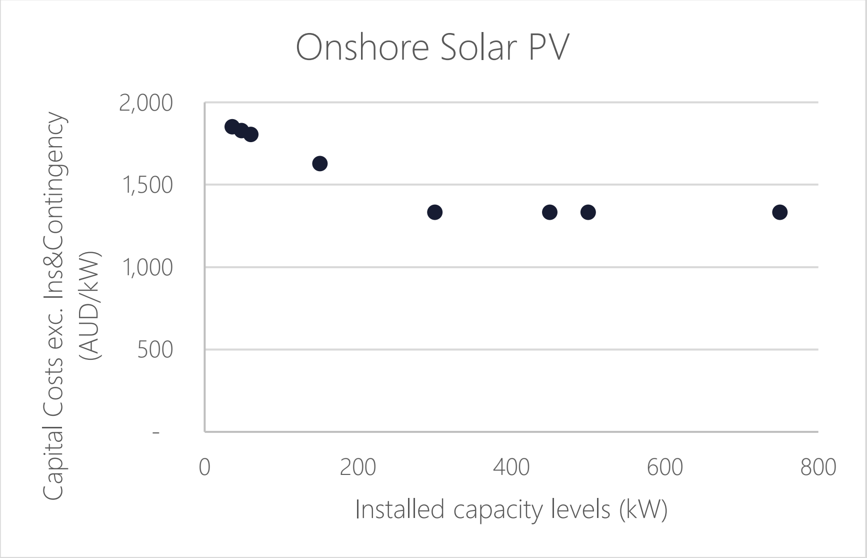


Figure 6-33. Capital costs for onshore solar PV excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity [12, 32].

Floating Solar PV (FPV)

The US based National Renewable Energy Laboratory (NERL) [33] conducted a bottom-up analysis of the installed costs for FPV systems deployed on artificial water bodies under average site conditions and estimated an installed system cost premium of 25% compared with ground-mounted PV installed over bare ground and that the largest contributors to this premium were higher structural costs related to the floats and anchoring system. Their analysis also suggested that the LCOE from FPV systems is around 20% higher than ground-mounted PV systems. As rooftop mounted PV systems are slightly more expensive than ground mounted PV systems, to the assumption was made that the capital costs of FPV, excluding insurance and contingency, would be 120% greater than the costs for Onshore Solar PV at the project site. See Figure 6-34. It was assumed that 3% of total capex would be spent on annual OPEX with the increase from 2% for onshore solar accounting for offshore maintenance activities.

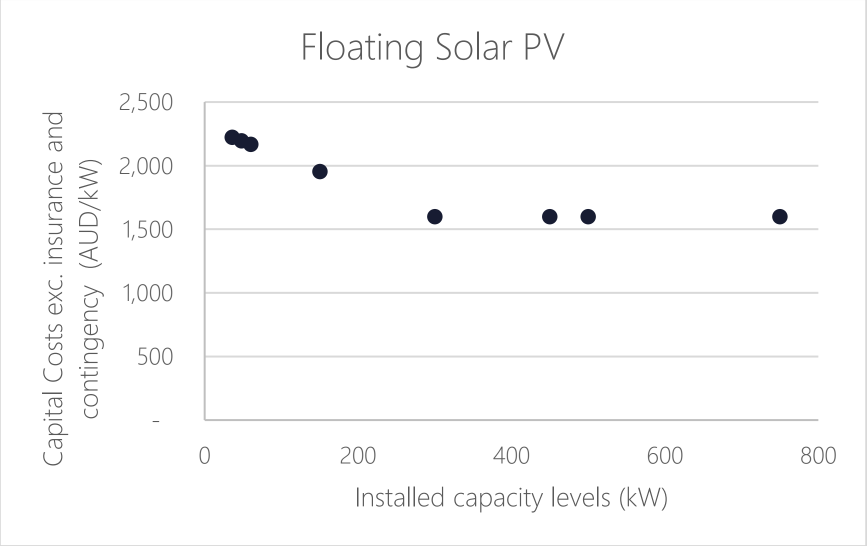


Figure 6-34. Capital costs for FPV excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [12, 32]).

Onshore Wind

NREL [13] estimated capital cost based on three differently rated power turbines of Residential Distributed Wind (20kW), Commercial Distributed Wind (100kW) and Land Based (2.6MW). Residential Distributed Wind turbines were used in scenarios 1 to 2 (12, 24, 36 and 48kW) and a sliding cost scale between the 100kW and 2.6MW references was used for scenarios 3 to 5. See Figure 6-35. Contingencies and insurance of 20% and 1% were applied to the capital cost subtotal. It was assumed that 3% of total capex would be spent on annual operating costs (OPEX)

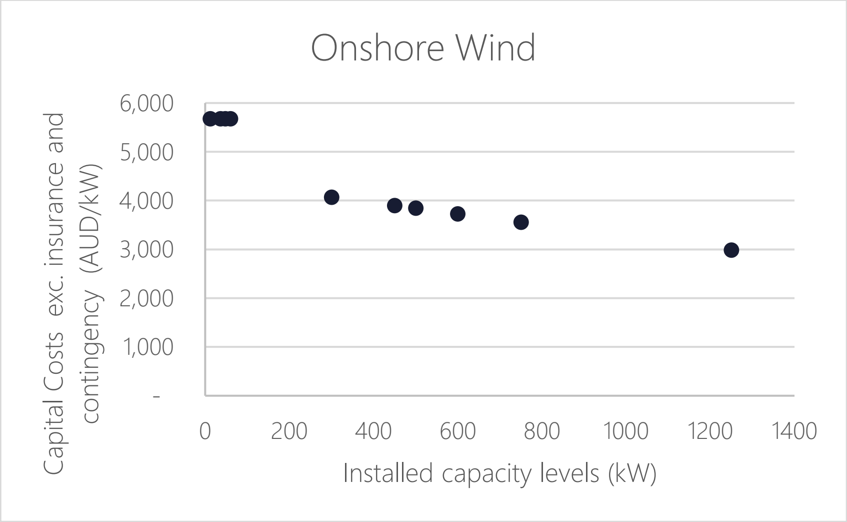


Figure 6-35. Capital costs for onshore wind implementation excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [13]).

Offshore Wind

NREL [13] has estimated capital costs for floating and fixed-bottom wind turbines with the rated power of 6.1 MW. Fixed bottom wind turbines were used as floating wind technology is more expensive at this time. The trends observed on onshore wind as installed capacity decreased were applied in a sliding scale throughout the proposed installed capacity scenarios. See Figure 6-36. Contingencies and insurance of 20% and 1% were applied to the capital cost subtotal. It was assumed that 3% of total capex would be spent on annual operating costs (OPEX).

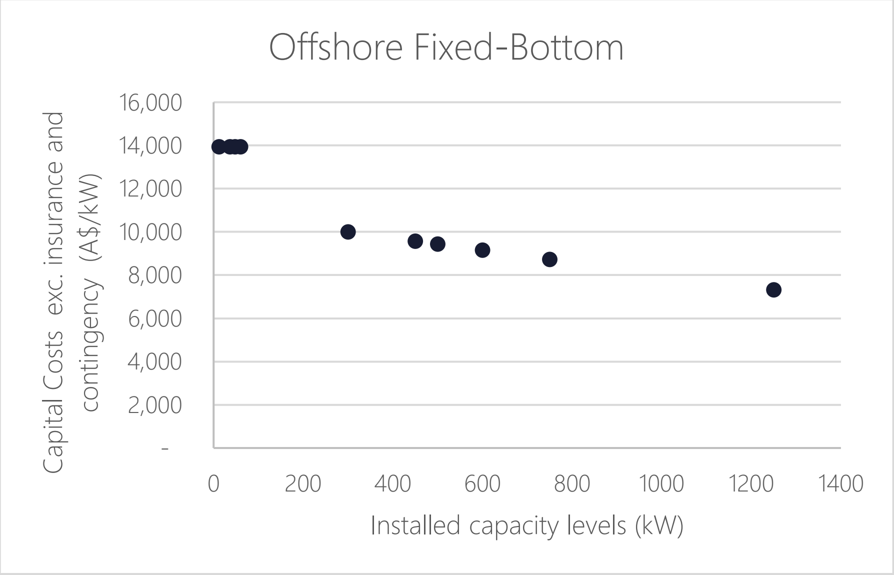


Figure 6-36. Capital costs for offshore wind – fixed bottom excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [13]).

Wave Energy

A 2022 real terms cost of A$15,500/kW was used throughout the various installed capacity levels in scenarios 1 to 5. This cost was calculated based on the projected capital cost for 1MW installed capacity of the Wave Energy Converter from WaveSwell [34]. Contingencies and insurance of 20% and 1% were applied to the capital cost subtotal. It was assumed that 2% of total capex would be spent on annual operating costs (OPEX) based on presumed OPEX/O&M figures from [34, 35].

Levelised cost of energy data

LCOE data for each energy system component was derived from publicly available data. A 2% inflation rate was assumed from 2022, a discount rate of 7% and a USD-AUD exchange rate of A$1.52 for $1 USD. Capital expenditure was assumed to start in 2023 for all energy deployments and useful asset life were assumed as 20.5 years for a wave energy converter, 25.5 years for solar Panels and 21.5 years for wind turbines.

LCOE is dependent on the scale of deployment, since economies of scale (i.e., the number of solar panels/wind turbines/wave devices) and scale (the size of devices and associated infrastructure) drive down cost. Figure 6-37 shows the relationship between the installed capacity of solar PV, and LCOE. This relationship is used in the energy system modelling, along with the LCOE of all other energy system components, to estimate the whole system LCOE.

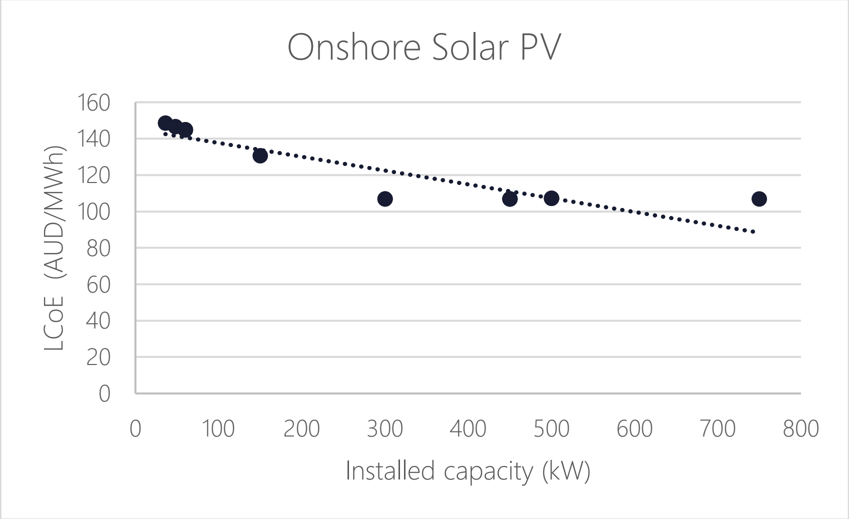


Figure 6-37. Onshore solar PV LCOEs calculated for the various scenarios for energy supply in Albany.

Figure 6-38 shows the relationship between the installed capacity of floating solar and LCOE. In general the LCOE of floating solar PV is approximately 30% higher than the LCOE of onshore solar PV because of the additional infrastructure and complexity in installing solar PV panels offshore. The linear line of best fit is used to determine the LCOE of floating offshore solar, depending on the capacity installed.

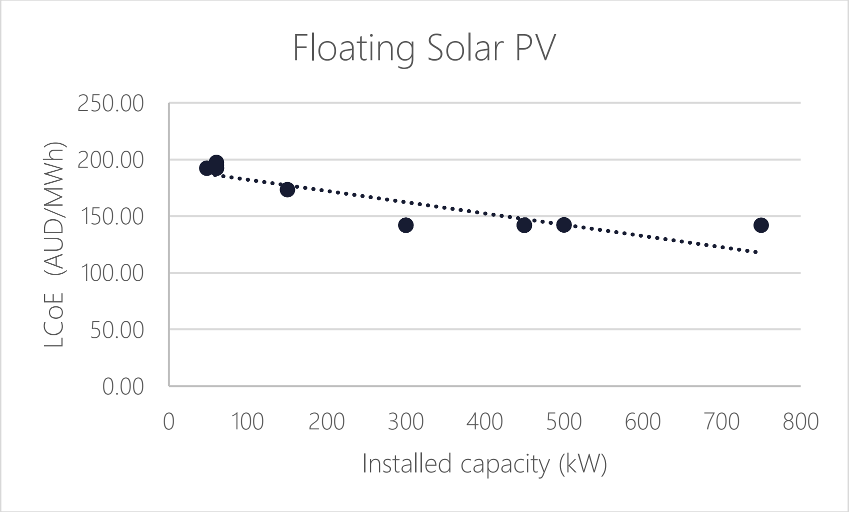


Figure 6-38. Floating solar PV LCOEs calculated for the various scenarios for energy supply in Albany.

Figure 6-39 shows the relationship between the installed capacity of onshore wind and LCOE. The linear line of best fit was used to determine the LCOE of onshore wind, depending on the capacity installed.

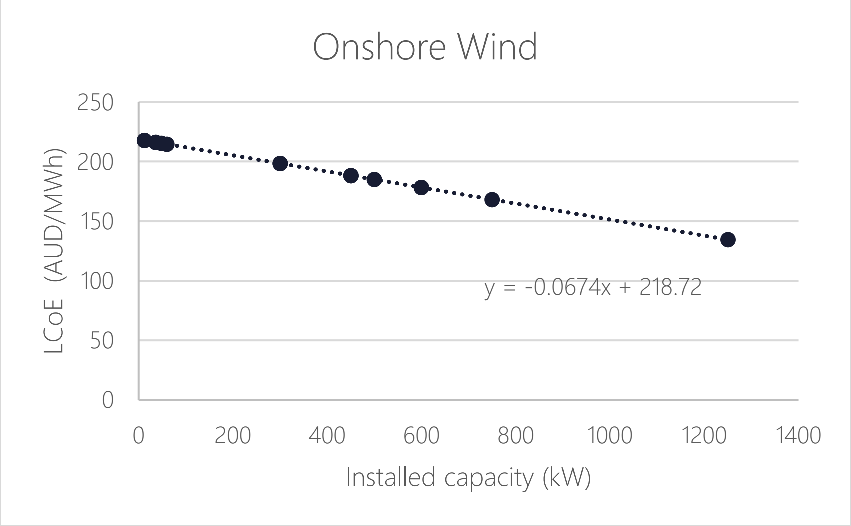


Figure 6-39. Onshore wind LCOEs calculated for the various scenarios for energy supply in Albany.

Figure 6-40Figure 6-40 shows the relationship between the installed capacity of offshore wind fixed bottom and its LCOE. The linear line of best fit was used to determine the LCOE of onshore wind, depending on the capacity installed.

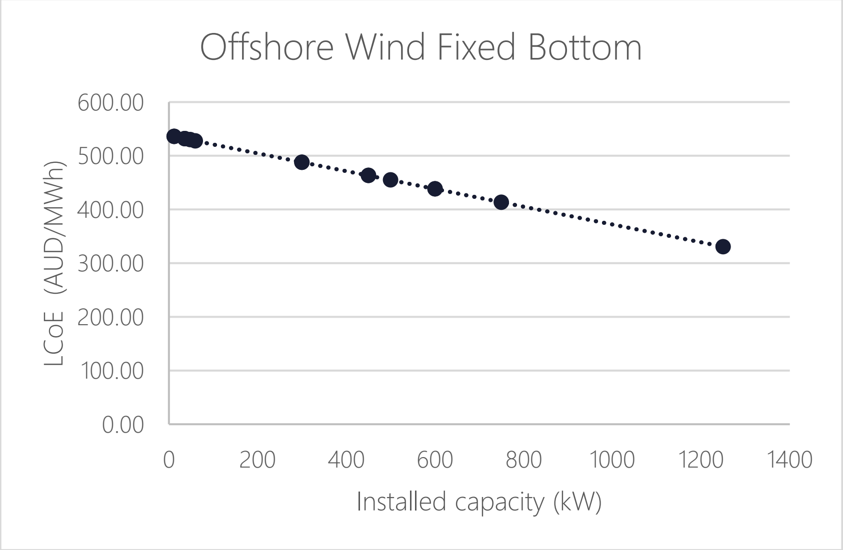


Figure 6-40. Offshore wind fixed bottom LCOEs calculated for the various scenarios for energy supply in Albany.

Figure 6-41 shows the relationship between the installed capacity of wave power and LCOE. The availability of cost data for wave devices is sparse than for solar PV and wind and thus, as explained before, the projected capital cost for 1MW installed capacity of the Wave Energy Converter from WaveSwell [34] was used. Applying to it contingencies and insurance of 20% and 1%, as well as 2% of total capex as OPEX [34, 35] resulted on a notably larger numerator for the LCOE than as originally calculated in the Wave energy cost projections from CSIRO [14]. The energy system modelling assumes the LCOE of wave energy is approximately A$900/MWh, regardless of the installed capacity installed (vs A$480/MWh in Table).

As explained earlier, under current trends and the proposed timetable, the Marketplace would not benefit from CAPEX reduction due to cumulative construction of wave energy capacity as forecast in future years in the Wave energy cost projections from CSIRO [14].

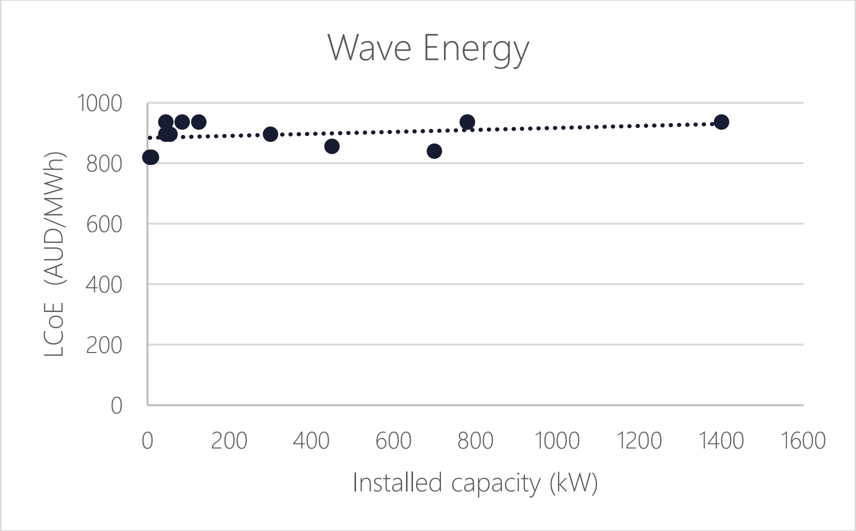


Figure 6-41. Wave energy LCOEs calculated for the various scenarios for energy supply in Albany.

Batteries

LCOSs for Lithium-ion and Vanadium redox-flow batteries were taken from [14], inflated to 2022 and converted into Australian Dollars: A$390 and A$455/MWh respectively. These LCOS were entered into the Energy System Modelling.

6.5.2 Energy System Model Outputs

The energy system model simulates the power flows between its components, as illustrated in Figure 6-30Figure 6-31. Example outputs from the energy system modelling over a 1-year period are illustrated in the plots below. Figure 6-42 shows the combined renewable power time series from solar PV, wind and wave energy generation. Figure 6-43 shows the annual demand profile. Demand increases slightly during winter months to account for additional heating load. Figure 6-44 shows the amount of renewable power that is used to balance demand directly. Figure 6-45 shows the surplus renewable power used to charge a battery. Figure 6-46 shows the surplus renewable power that must be curtailed. Finally, Figure 6-47 shows the reserve power that is used to fully balance demand at times when power from renewables cannot.

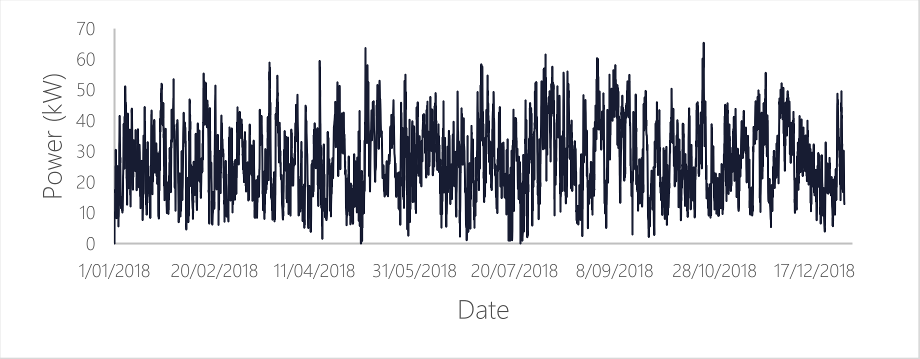


Figure 6-42. Renewable power generation example.

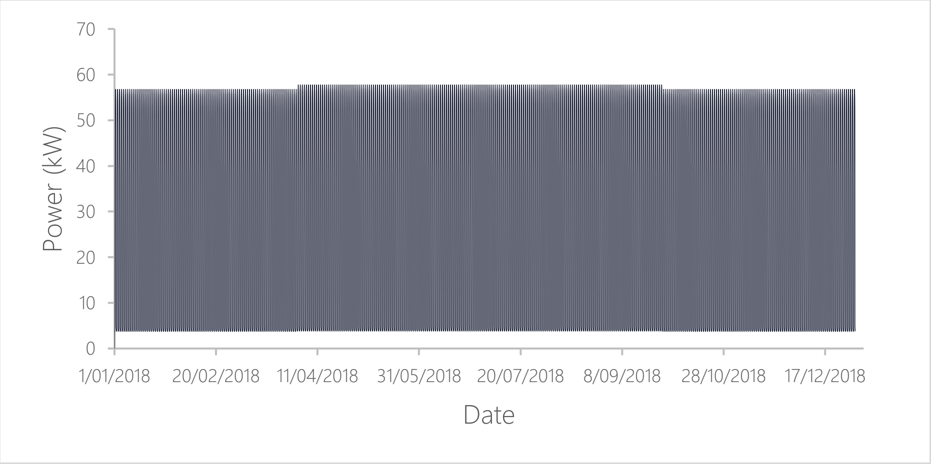


Figure 6-43. Electricity demand example.

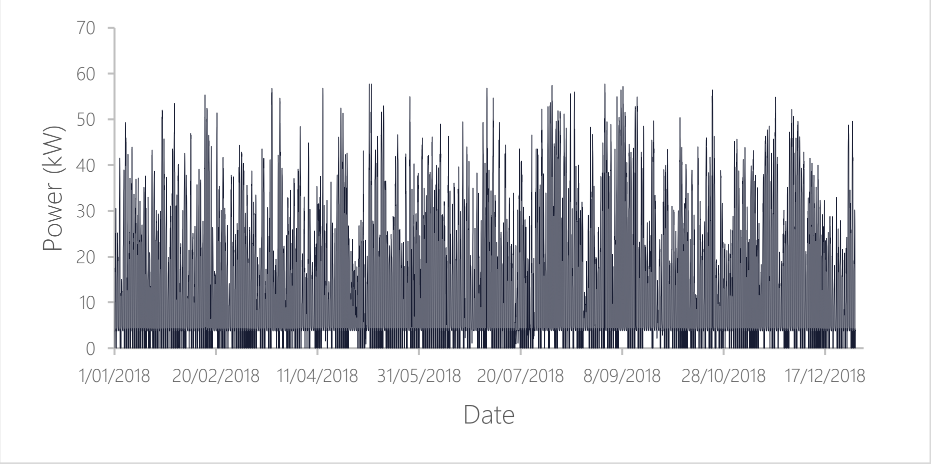


Figure 6-44. Renewable power to demand example.

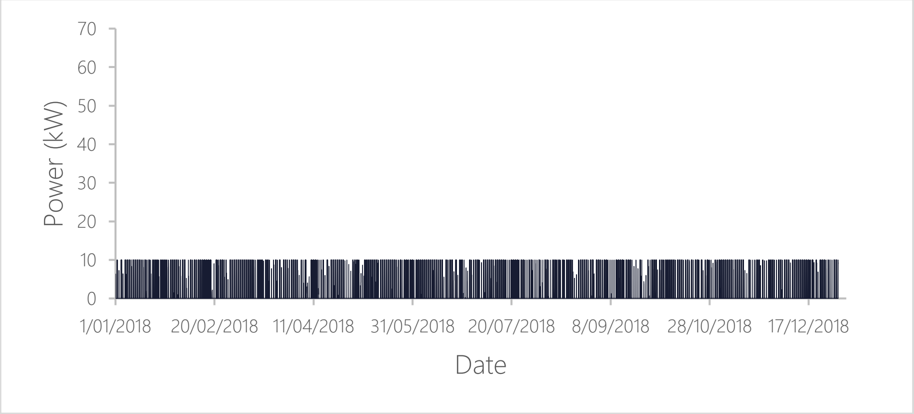


Figure 6-45. Renewable power to battery example.

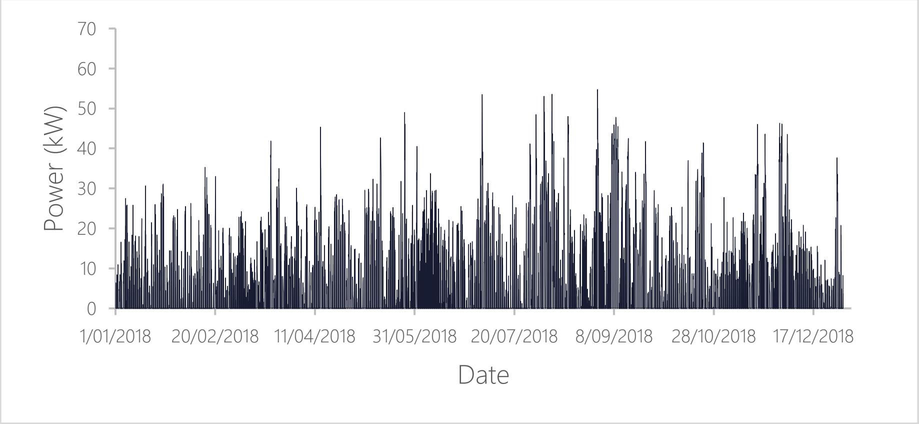


Figure 6-46. Curtailed renewable power example.

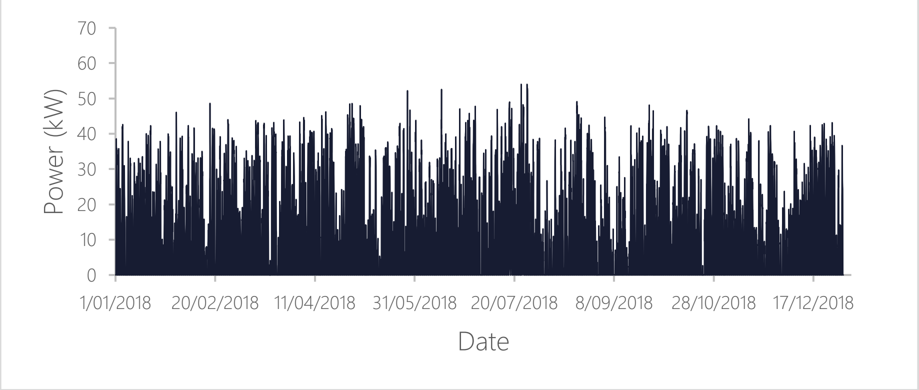


Figure 6-47. Reserve power to demand example.

To assess the annual performance of the energy systems, techno-economic performance indicators are used. These include the following:

- **Supply and demand balancing:** Unlike conventional fossil fuel power generation technologies, renewable power is not dispatchable (i.e., it is not capable of turning power up or down to match demand). Instead, renewable power generation varies with time in a manner that cannot easily be match to demand. To quantify the level of supply demand balancing, the energy system modelling quantifies the reserve energy requirement, and curtailment;

    - **System resilience (reserve energy requirement):** The resilience of an energy system is related to the amount it relies on external or additional supply to fully balance demand. The energy system modelling quantifies the reliance of each system on a reserve power source to balance demand with supply. The maximum reserve power is also quantified to help establish the specification of reserve power supply required for supply and demand balancing in periods when demand far exceeds supply.
    - **Curtailment:** Given the temporal variability in renewable power generation, there may be a need to curtail excess renewable power when it cannot be absorbed by the energy system (i.e., absorbed by being used to meet demand or charge the energy storage system).

- **System levelized cost of energy (LCOE).** LCOE is the ratio between the total costs to the energy produced over the project lifetime;

$$LCoE = \sum_{t=1}^{n} \frac{\frac{C_t+O_t+F_t}{(1+r)^t}}{\frac{E_t}{(1+r)^t}}$$

where t is the year, n is the lifetime of the project in years, C_t, O_t and F_t are the capital, operations and maintenance and fuel costs in year t respectively, r is the discount rate (i.e., the rate of return used to discount future cash flow back to present value), and E_t is the energy produced in year t. LCOE is a common metric used to assess the economic viability of projects. The LCOE of each individual energy system component (i.e., each renewable power source, the energy storage system, and the reserve power) is calculated based on its cost and the amount of energy it provides to the energy system. Each of these constituent LCOE's are combined to provide a system LCOE.

6.5.3 Energy System Optimisation

The energy system model is used to establish the combination of renewable power and energy storage technologies that maximises the system's performance. In this study the main objectives of the energy system are as follows:

1. Minimise whole-system cost of energy
2. Maximise system resilience
3. Demonstrate offshore renewable technologies
4. Maximise technology readiness level (TRL)

The energy system model is used to establish the most appropriate combinations of renewable and energy storage technologies that satisfy these four objectives. To do this, an optimisation approach is undertaken. In this approach, the energy system model is simulated over a wide range of renewable power capacity mixes (i.e., where the proportion of solar PV, wind and wave that makes up total renewable supply is varied across a range of capacity cases). For each capacity case, the performance of the energy system is quantified using the techno-economic performance indicators described above. These performance indicators are used to compare the performance of each capacity case, to then make recommendations on the capacity cases(s) that best fulfil the objectives of the system design.

It is important to acknowledge that often, the objectives of the energy system design are often conflicting. For example, minimising whole-system cost of energy can reduce system resilience. When this is the case, there is a need to assess the trade-offs between the energy system objectives. Through the adoption of the brute-force optimisation method, 'near-optimal' design solutions can be sought that balance cost and resilience for example. To quantify the difference in energy system performance that arises when prioritising cost over resilience, resilience over cost, and a balance between cost and resilience, results are presented that reflect three possible solutions, as described below:

a. **High cost & resilience:** Maximisation of system resilience is prioritised.
b. **Intermediate cost/resilience:** Both system cost and system resilience are prioritised.
c. **Low cost & resilience:** Minimisation of system cost is prioritised.

6.6 Energy System Modelling Results

6.6.1 Overview of Findings

Results from energy system modelling show that in general, the following measures enhance supply-demand balancing to improve system resilience, but to the increase of the whole-system LCOE, which in turn must be compared to the end-users' cost of energy:

1. **Installing wave energy at high levels relative to solar PV and/or wind.** Diversifying the renewable power mix in this way helps to enhance supply-demand balancing because the solar PV, wind and wave power time series are different enough that they complement each other (I.e., when solar PV power is low, wind and/or wave are often high), thereby reducing reliance on reserve power.
2. **Oversizing renewable power generation.** By oversizing renewable power generation, annual renewable energy production exceeds annual energy demand, which increases the likelihood that demand can be met with supply at any point in time. Oversizing renewable capacity also increases curtailment, because the proportion of renewable energy that is absorbed (I.e., used to meet demand or stored in the battery) usefully by the system reduces, leading to an increase in system LCOE. The low cost/resilience options demonstrate relatively modest increases in system LCOE of around 10% by oversizing renewable power, and relatively large reductions in reliance on reserve power, of around 55%. This is highlighted as a possible opportunity for further investigation from a business case perspective, to enhance system resilience at potentially acceptable cost.
3. **Installing short duration energy storage.** This helps reduce dependency on reserve power by reducing curtailment. It is important to note that there is a limit to the amount of energy storage that can be installed before the load factor of the energy storage system falls below acceptable limits. The load factor quantifies the utilisation of the energy storage system. If the energy storage system is underutilised, its cost becomes unacceptably high. In all system designs, there is need for reserve power, highlighting the challenging nature of creating a fully off-grid energy system.

These trade-offs between system resilience and cost means there is no single 'optimal' energy system design, that achieves both low cost and high resilience. Instead, the energy system design must reflect the compromise between cost and resilience. These trade-offs are described further here with respect to the five demand scenarios.

6.6.2 Scenario 1 – Early Deployment

System Requirements

All supply and demand data has been modelled to ascertain the optimal combination of solar PV, wind and wave installed capacities to minimise the annual energy shortage required, and in turn back-up electricity supply. Three options are presented in Table 6-18Table 6-18. Option 1a minimises the reliance on back-up supply over a year, Option 1b uses an intermediate level of wave capacity and Option 1c uses no wave capacity.

Table 6-18. Scenario 1 – summary of installed capacity options and their reliance on back-up supply.

OPTION	SOLAR PV	WIND	WAVE	RESERVE ENERGY
1a: High cost/resilience	60 kW	12 kW	45 kW	60 MWh
1b: Intermediate cost/resilience	60 kW	24 kW	25 kW	62 MWh
1c: Low cost/resilience	36 kW	48 kW	0 kW	80 MWh

Energy system performance

Figure 6-48 provides the system LCOE of the high (1a), intermediate (1b) and low (1c) cost/resilience options. Results demonstrate how the system LCOE is impacted by the battery power rating (ranging from no battery to a total battery power rating of 50 kW), and also the impact of oversizing renewable generation by 50%. In general, oversizing of renewable generation increases system LCOE by 7-20%. This is because oversizing renewable generation increases curtailment, resulting in a reduction in the proportion of renewable generation that is used by the system. This causes the LCOE of solar PV, wind and wave to increase, since LCOE is the ratio of the total DEVEX/CAPEX/OPEX costs to the useful energy supplied to the system.

In the low cost/resilience Option 1c, a system LCOE of A$277/MWh is achieved by installing solar PV (36 kW) and wind (60 kW) only. Option 1b demonstrates an increase in system LCOE of 35% relative to 1c. Option 1a has an LCOE that is 71% greater than Option 1c.

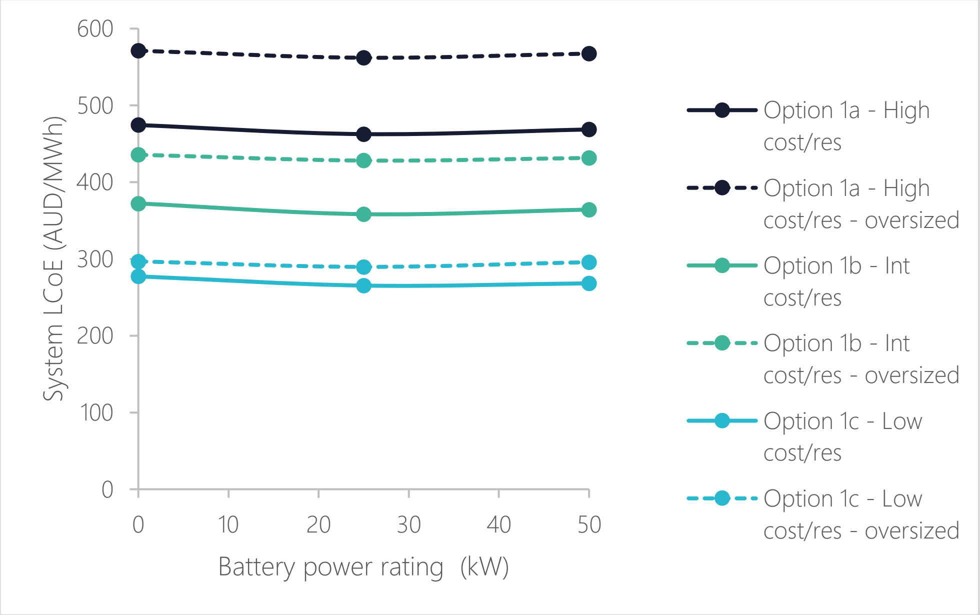


Figure 6-48. System LCOE of the high, intermediate and low cost/reliance Scenario 1 options, with and without renewable generation oversizing, and a range of energy storage capability.

Introducing energy storage to the systems has a very limited impact on system LCOE. In general, LCOE is minimised using the 25kW battery, but not by a significant amount relative to the other two cases considered (i.e., with either no battery, or the 50kW battery). The reason for this is that when battery storage is introduced, it helps limit reliance on reserve power, but the reserve supply LCOE and the Levelized Cost of Storage (LCOS) are approximately the same (around A$250/MWh). Adding additional battery capacity to the 25kW battery results in a small increase in system LCOE. This occurs because as battery capacity is increased, the ability of the additional battery capacity to absorb surplus renewable power begins to diminish. This means that whilst adding this additional battery capacity to the system does result in a reduction in the reserve energy requirement, it is not enough to outweigh the cost of the additional battery capacity.

It is also important to acknowledge that the viability of adding battery capacity is dependent on the source and cost of reserve power. If the cost of reserve power far outweighs the cost of storage, storage becomes a far better proposition economically. This point is further illustrated in Figure 6-49 which shows how the annual reserve energy needed by the system is impacted by the battery power rating and oversizing of renewable generation. In general, by adding energy storage capacity to the system up to 50 kW/100 kWh, annual reserve energy requirement reduces by 10-15% in all options, by enhancing balancing between renewable supply and demand.

Figure 6-49 shows that in general, 50% oversizing of renewable generation results in reduction in annual reserve energy requirement of 55-75%. This may provide a good opportunity to enhance system resilience, since oversizing renewable generation using the low cost/resilience system shows only modest increases in system LCOE, as shown in Appendix 1. This includes a breakdown of the estimated system LCOE for different combinations of onshore/offshore solar PV and wind.

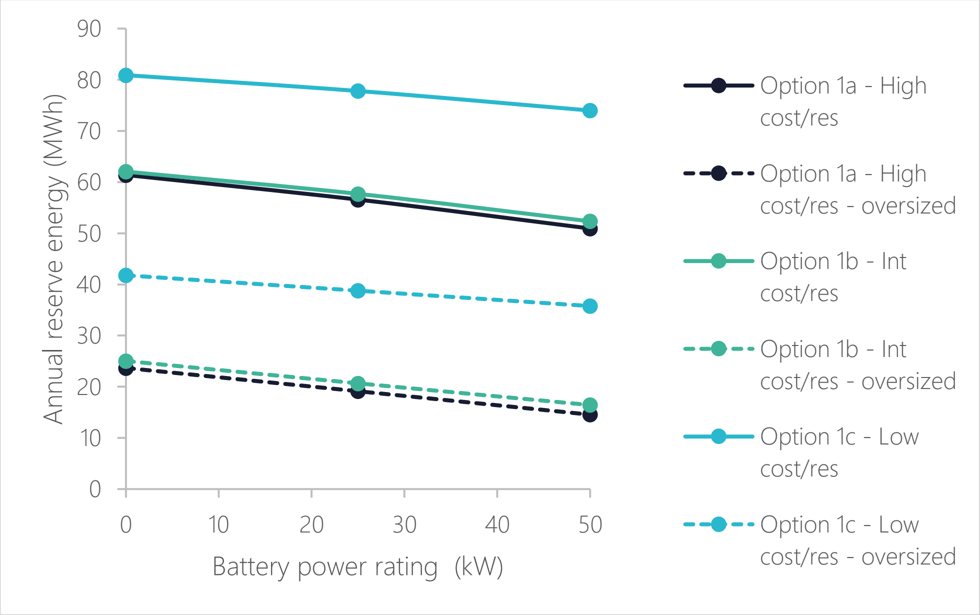


Figure 6-49. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance scenario 1 options, with and without renewable generation oversizing.

Recommendations

Energy system model results provide insights into the sensitivity of the energy system performance to changes in the renewable supply mix, and oversizing of renewables. Based on these results, Option 1c, comprising of 36kW of solar PV, 48kW of wind and 0kW of wave energy, achieves the lowest system LCOE solution. Given the relatively low energy demand in Scenario 1, it is recommended that wave energy is demonstrated using a device not connected to the grid, so demonstration of the device will rely on data from on-board sensors, video and drone footage or similar. This aligns well with the deployment of UWA's M4 wave energy converter, where real time data can be transmitted to a demonstrator device, providing simulated inputs at low cost. If needed, the most cost-effective way to demonstrate grid connected offshore power will be to use floating solar PV, which increases the system cost by 4%, to A$288/MWh. There is also opportunity to connect a small-scale wave energy device at this phase, as an early input to the expanded marketplace facility

This system will require 81MWh of reserve energy supply in the absence of any energy storage. Adopting a 25kW, 50kWh short duration energy storage system reduces the dependency on reserve energy supply by 4%, to 78MWh. Given the small improvement to system LCOE from adding this battery capacity, its viability will likely be dictated by its capital cost.

Oversizing of renewable generation in the low cost/resilience options results in a relatively modest increase in system LCOE of 12%, and a reduction in reliance on reserve energy of 55%. In these options, oversizing may provide an opportunity to enhance system resilience at acceptable cost. Further investigation is required to understand this trade-off between system costs and resilience, with consideration for the increased capital cost from oversizing of renewable generation.

6.6.3 Scenario 2 – Base Case Deployment

System Requirements

All supply and demand data has been modelled to ascertain the optimal combination of solar PV, wind and wave installed capacities so that the annual energy shortage is minimised, that is, reliance on a back-up supply is minimised. Three such options are presented in Table 6-19. Option 2a minimises the reliance on back-up supply over a year, Option 2b uses an intermediate- wave power capacity, and Option 2c neglects the use of wave power.

Table 6-19. Scenario 2 – summary of installed capacity options and their reliance on back-up supply.

OPTION	SOLAR PV	WIND	WAVE	BACK-UP
2a High cost/resilience	60 kW	12 kW	55 kW	60 MWh
2b: Intermediate cost/resilience	60 kW	36 kW	10 kW	64 MWh
2c Low cost/resilience	48 kW	48 kW	0 kW	75 MWh

Energy system performance

Figure 6-50 shows the system LCOE of the high (2a), intermediate (2b) and low (2c) cost/resilience options, over a range of battery solutions, and Options where renewable supply is oversized by 50%. The trends demonstrated here are very similar to those illustrated in Scenario 1. There is an increase in system LCOE with oversizing of renewable generation. Furthermore, the introduction of battery storage has very little impact on system LCOE. In the low cost/resilience option (2c), system LCOE is minimised using the 25kW battery without oversizing, to A$252/MWh.

This is A$13/MWh lower than the lowest system LCOE in Scenario 1. System LCOE increases to of A$285/MWh and A$490/MWh in options 2b and 2a respectively.

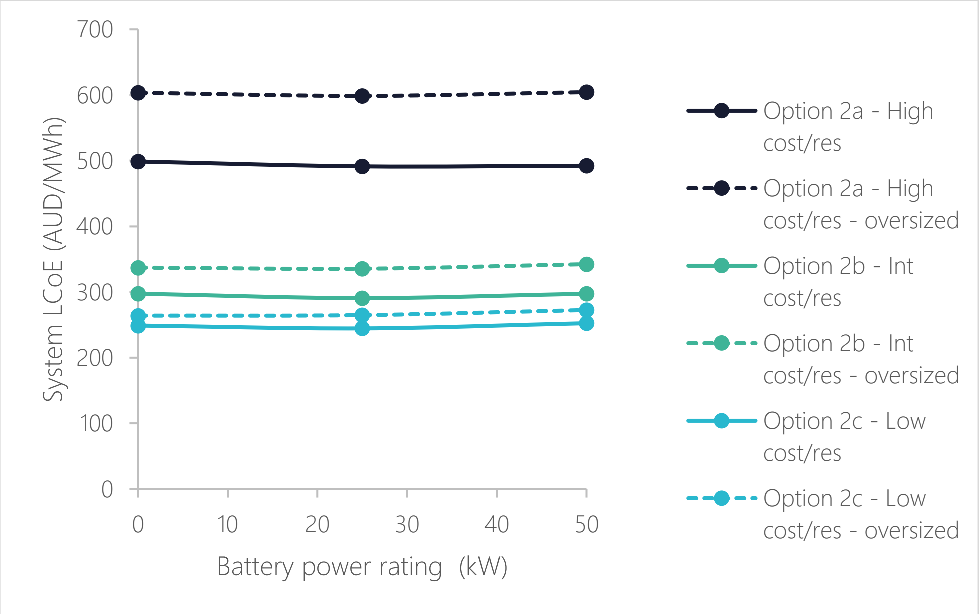


Figure 6-50. System LCOE of the high, intermediate and low cost/reliance Scenario 2 options, with and without renewable generation oversizing, and a range of energy storage capability. Figure 6-51. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 1, with and without renewable generation oversizing.

Figure 6-51 shows how the annual reserve energy needed by the system is impacted by the battery power rating and oversizing of renewable generation. In general, adding energy storage capacity results in 50-80% reduction in annual reserve energy requirement. Given the relatively low impact introducing battery storage has on system LCOE, the use of battery storage may provide a good opportunity to enhance system resilience at relatively low cost.

Figure 6-51 also shows that oversizing renewable power generation also results in significant reductions in reserve energy reliance. However, oversizing may only be a viable option in options 2b and 2c. This is because option 2a shows a very high increase in system LCOE by introducing oversizing, since it is driven predominantly by the wave LCOE which is the main source of renewable power.

Appendix A (Second table) provides an extended summary of all Scenario 2 energy system results. This includes a breakdown of the estimated system LCOE for different combinations of onshore/offshore solar PV and wind.

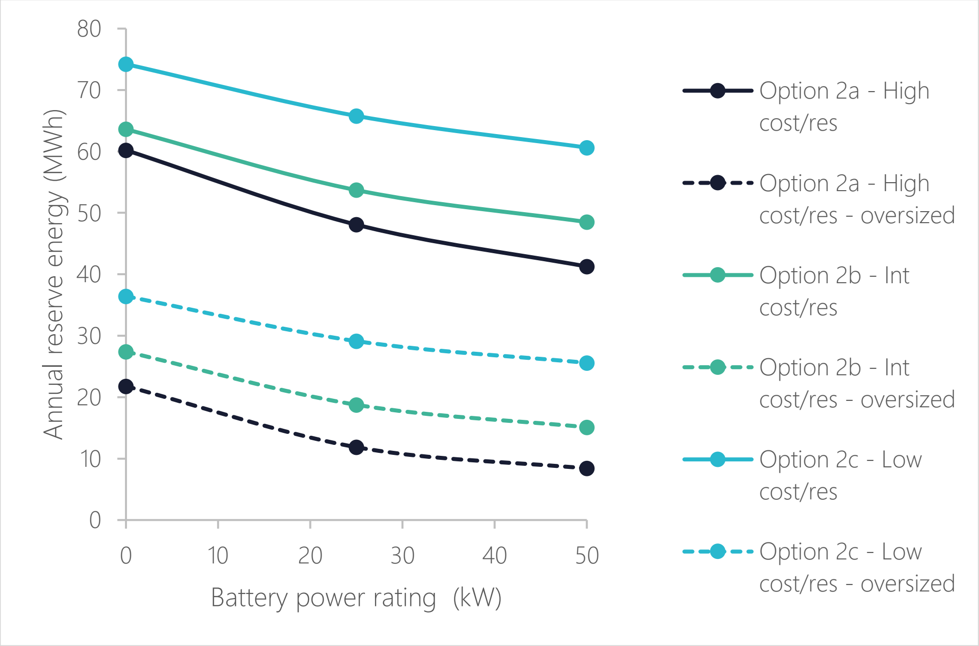


Figure 6-51. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 1, with and without renewable generation oversizing.

Recommendations

As with Scenario 1, a fully informed recommendation can only be made after a full business case analysis has been completed. Nevertheless, energy system modelling results show that Option 2c, comprising of 48kW of solar PV, 48kW of wind and 0kW of wave energy, appears favourable from a techno-economic standpoint for Scenario 2. As is the case also in Scenario 1, the demand is not large enough to warrant a grid connected wave energy converter and the most cost-effective way to demonstrate grid connected offshore power would be to use floating solar PV, which increases system LCOE by 5% relative to the option with onshore grid connected renewables only, from A$245/MWh to A$258/MWh. The system will require 66MWh of reserve energy supply in the absence of any energy storage. Adopting a 25kW, 50kWh short duration energy storage system reduces the dependency on reserve energy supply by 8%, to 61MWh.

However, having the capacity to demonstrate wave energy as a component of a microgrid is a material requirement of the marketplace, which leads to a preference for scenario 2b or a variation of it.

As with Scenario 1, in Scenario 2 oversizing of renewable generation results in relatively modest increases in system LCOE, and high reductions in reliance on reserve energy.

6.6.4 Scenario 3 – The Wider Region

System Requirements

Three options are presented in Table 6-20. Option 3a minimises the reliance on back-up supply over a year, Option 3b uses an intermediate wave power capacity and Option 3c uses aa low level of wave capacity.

Table 6-20. Scenario 3 – summary of installed capacity options and their reliance on back-up supply.

OPTION	SOLAR PV CAPACITY	WIND CAPACITY	WAVE CAPACITY	BACK UP SUPPLY REQ'D
3a: High cost/resilience	300 kW	300 kW	700 kW	439 MWh
3b: Intermediate cost/resilience	300 kW	450 kW	450 kW	528 MWh
3c: Low cost/resilience	450 kW	600 kW	85 kW	693 MWh

Energy system performance

Figure 6-52 provides the system LCOE of the high (3a), intermediate (3b) and low (3c) cost/resilience options to show how the system LCOE in Scenario 3 is impacted by the battery power rating and oversizing of renewable generation. As is similar in all scenarios, oversizing of renewable generation increases system LCOE considerably in option 3a, whilst the introduction of battery storage has a very limited impact on system LCOE. System LCOE is minimised to A$252/MWh in option 3c, which uses 450kW of solar PV, 600kW of wind, and 85kW of wave. Unlike scenarios 1 and 2, wave capacity has been introduced in the low cost/resilience (3c) option here because it becomes easier to absorb the high wave LCOE when overall renewable supply is higher. This is because (I) the LCOE of solar and wind falls with the size of their installed capacity, to help offset the high wave cost, and (ii) it becomes easier to absorb high wave costs when renewable power generation is relatively high, because wave capacity is a low proportion of total renewable capacity.

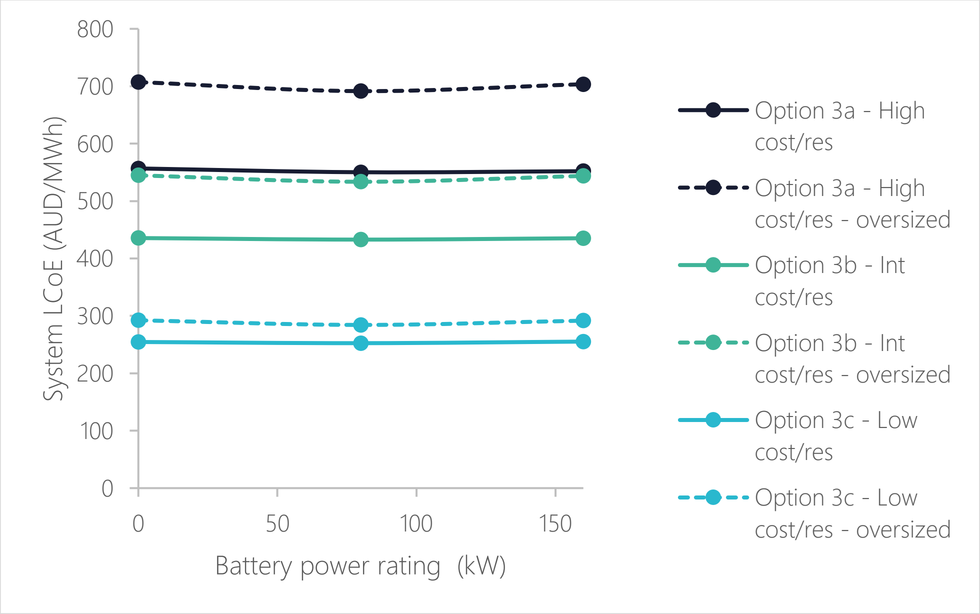


Figure 6-52. System LCOE of the high, intermediate and low cost/reliance scenario 3 options, with and without renewable generation oversizing, and a range of energy storage capability.

Figure 6-53 shows how the annual reserve energy needed by the system is impacted by the battery power rating and oversizing of renewable generation. In general, adding energy storage capacity results in modest reductions in annual reserve energy requirement. In comparison to Scenarios 1 and 2, the use of battery storage appears potentially less attractive for this reason but requires further investigation within the business case assessment to establish the impacts of added CAPEX by introducing battery storage.

Figure 6-53 also shows that oversizing renewable power generation results in significant reductions in reserve energy reliance. As is the case in Scenarios 1 and 2, oversizing is likely to only be a viable option in options 3b and 3c because option 3a shows a very high increase in system LCOE by introducing oversizing, given that wave power is the main source of renewable power.

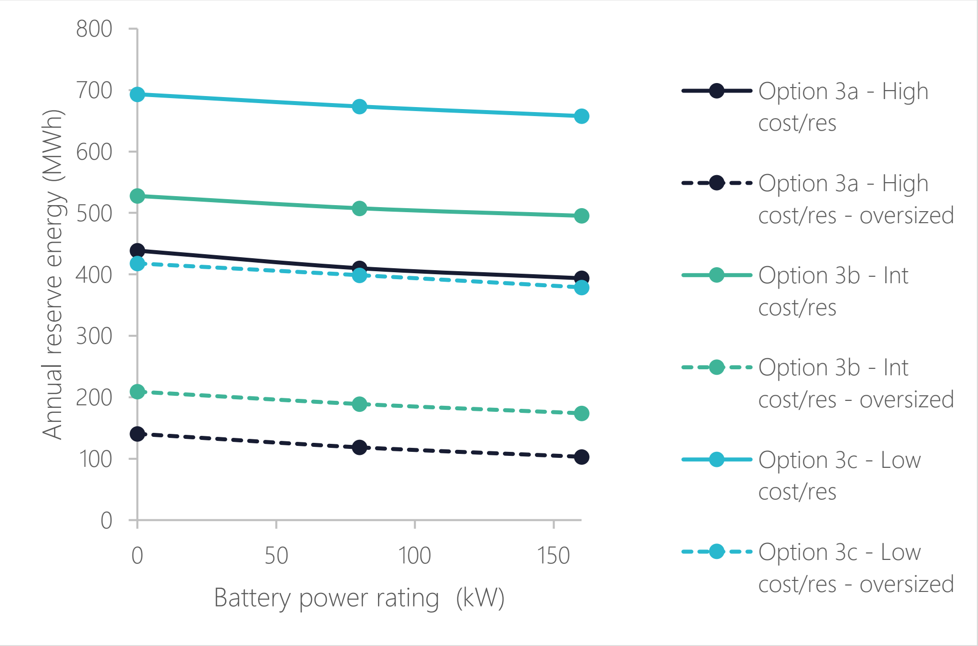


Figure 6-53. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance Options for Scenario 1, with and without renewable generation oversizing.

Appendix 1 - provides an extended summary of all Scenario 3 energy system results. This includes a breakdown of the estimated system LCOE for different combinations of onshore/offshore solar PV and wind.

Recommendations

The main recommendations for Scenario 3 are reserved for after a business case analysis, which is necessary to fully assess the impacts of adopting wave power capacity within the renewable supply mix. Instead, recommendations here are kept general to comment on general trends that are likely to dictate the suitability of each system design.

In Scenario 3, it becomes possible to install wave capacity whilst maintaining similar system LCOE to Scenarios 1 and 2, because the added wave cost can be partly absorbed by the lower solar and LCOE when installed in larger amounts, and the proportion of wave power can be kept low relative to solar and wind. The low cost/resilience Option 3c considered in this scenario uses 85kW of wave, 450kW of solar PV, and 600kW of wind. Increasing wind capacity will result in significant increases to energy system cost, and significant improvements to balancing to reduce reliance on reserve power.

Oversizing renewable generation by 50% appears to be unfeasible in options 3a and 3b, as it leads to very high increases in system LCOE. This may not be the case in Option 3c, assuming the capital cost of oversizing can be overcome.

6.6.5 Scenario 4 – Discovery Bay Expansion

System Requirements

All supply and demand data has been modelled to ascertain the optimal combination of solar PV, wind and wave installed capacities so that the annual energy shortage is minimised, that is, reliance on a back-up supply is minimised. These three options are presented in Table 6-21. Option 4a minimises the reliance on back-up supply over a year, Option 4b uses intermediate wave power capacity and Option 4c uses a low-level of wave capacity.

Table 6-21 Summary of installed capacity options and their reliance on back-up supply.

OPTION	SOLAR PV CAPACITY	WIND CAPACITY	WAVE CAPACITY	BACK UP SUPPLY REQ'D
4a: High cost/resilience	300 kW	450 kW	450 kW	1000 MWh
4b: Intermediate cost/resilience	450 kW	450 kW	300 kW	1000 MWh
4c: Low cost/resilience	450 kW	600 kW	45 kW	1375 MWh

Energy system model results

Figure 6-54 provides the system LCOE of the high (4a), intermediate (4b) and low (4c) cost/resilience options. Results demonstrate how the system LCOE is impacted by the battery power rating (ranging from no battery to 160 kW), and also the impact of oversizing renewable generation by 50%. In general, oversizing of renewable generation increases system LCOE by 10-30%. This is because oversizing renewable generation increases curtailment, resulting in a reduction in the proportion of renewable generation that is used by the system. This causes the LCOE of solar PV, wind and wave to increase, since LCOE is the ratio of the DEVEX/CAPEX/OPEX costs to the useful energy supplied to the system. The increase in system LCOE from oversizing is least extreme in the low cost/resilience Option 4c, as wave power makes up a small proportion of the total renewable capacity.

In Option 4c, a system LCOE of A$240/MWh is achieved by limiting wave capacity to 45kW, based on the three options considered. This increases to A$360/MWh and A$600/MWh in options 4b and 4a respectively. These proliferations of system LCOE represent 50% and 150% increases relative to the low cost/resilience option. Figure 6-54 shows that introducing energy storage to the systems has a very limited impact on system LCOE. In general, LCOE is minimised using the 80kW battery, but not by a significant amount relative to the other two cases considered (I.e., with either no battery, or the 160kW battery).

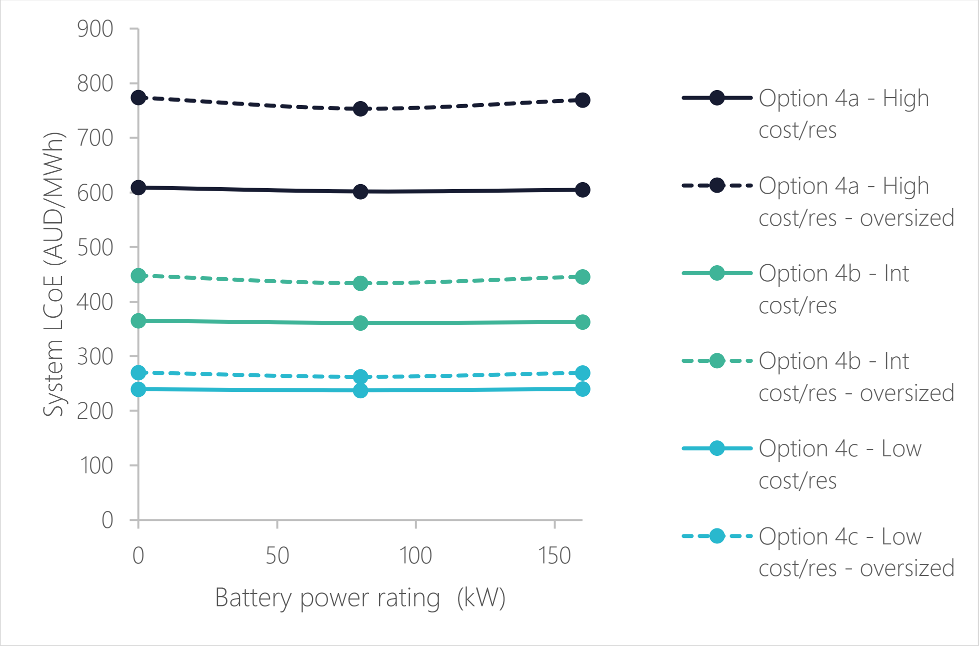


Figure 6-54. System LCOE of the high, intermediate and low cost/reliance options for Scenario 4, with and without renewable generation oversizing, and a range of energy storage capability.

Oversizing renewable generation reduces the systems reliance on reserve power significantly. This is shown in Figure 6-55. In general, oversizing of renewable energy production by 50% results in a 50-70% reduction in annual reserve energy requirement.

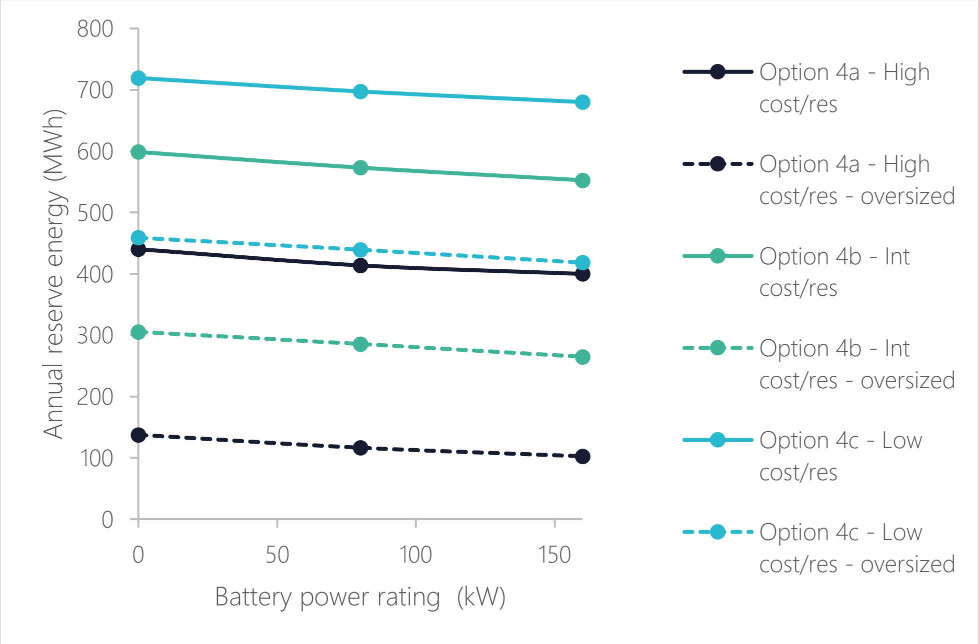


Figure 6-55. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 4, with and without renewable generation oversizing.

Appendix 1 – provides a summary of all Scenario 4 energy system results. This includes a breakdown of the estimated system LCOE for different combinations of onshore/offshore solar PV and wind.

Recommendations

As with Scenario 3, the main recommendations for Scenario 4 are reserved for after a business case analysis to fully assess the impacts of adopting wave power capacity within the renewable supply mix. Instead, recommendations here are kept general to comment on general trends that are likely to dictate the suitability of each system design.

Option 4c maintains a relatively low system LCOE of around A$240/MWh, using 45kW of wave energy capacity. This level of wave capacity is relatively low compared with the power rating of devices currently being developed, and so the availability of such a device, which may need to be bespoke, remains to be confirmed. Increasing wave capacity further, like in Option 4b results in a significant increase in the system LCOE, of 35%. If this cost increase is prohibitively high, the cheapest alternative for grid connected offshore renewables is floating solar PV.

Oversizing renewable generation by 50% is unlikely to be economically viable in Option 4a, given the resulting 30% increase in system LCOE. Options 4b and 4c show more modest increases in system LCOE from oversizing of renewable generation, of around 10-20%.

6.6.6 Scenario 5 - All In

System Requirements

All supply and demand data has been modelled to ascertain the optimal combination of solar PV, wind and wave installed capacities so that the annual energy shortage is minimised, that is, reliance on a back-up supply is minimised. Three such options are presented in Table 6-22. Option 5a minimises the reliance on back-up supply over a year, Option 5b uses an intermediate level of wave power capacity and Option 5c uses a low level of wave capacity.

Table 6-22. Scenario 5 – summary of installed capacity options and their reliance on back-up supply.

OPTION	SOLAR PV CAPACITY	WIND CAPACITY	WAVE CAPACITY	BACK UP SUPPLY REQ'D
5a: High cost/resilience	500kW	500 kW	1400 kW	810 MWh
5b: Intermediate cost/resilience	750 kW	750 kW	780 kW	1000 MWh
5c: Low cost/resilience	500 kW	1250 kW	125 kW	1375 MWh

Energy system performance

Figure 6-56 shows the system LCOE of the high (5a), intermediate (5b) and low (5c) cost/resilience options, over a range of battery solutions, and additional options where renewable supply is oversized by 50%. System LCOE is minimised to A$220/MWh using 500 kW of solar PV, 1250 kW of wind and 125 kW of wave power (I.e., option 5c), without oversizing of renewable power, and a 100kW battery. This increases to A$400/MWh and A$570/MWh in Options 5b and 5a respectively. As with all other scenarios, oversizing renewable generation results in a modest increase in system LCOE of the low cost/resilience option (5c), of around 7%, and far greater increases in the system LCOE in the intermediate and high cost/resilience options.

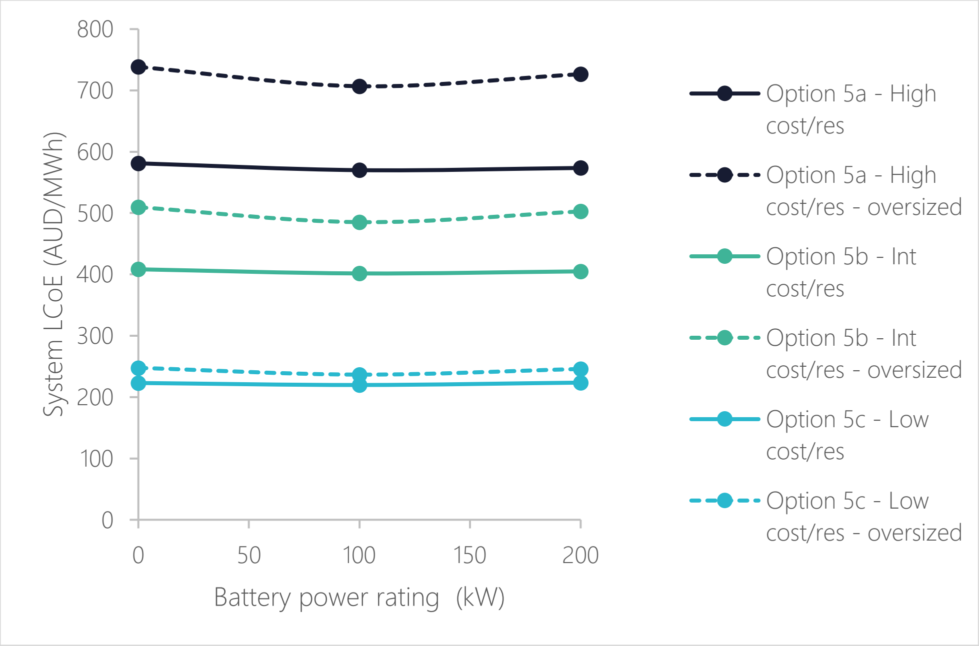


Figure 6-56. System LCOE of the high, intermediate and low cost/reliance options for Scenario 5, with and without renewable generation oversizing, and a range of energy storage capability.

Figure 6-57 shows how the annual reserve energy needed by the system is impacted by the battery power rating and oversizing of renewable generation. As has been seen in previous scenarios, adding energy storage results in relatively modest enhancements to supply-demand balancing, that only results in a reduction in system LCOE up to a battery rated power of 100 kW. Oversizing renewable generation reduces the systems reliance on reserve power significantly. In general, oversizing of renewable energy production by 50% results in a 40-70% reduction in annual reserve energy requirement.

Appendix 1 – provides a summary of all Scenario 5 energy system results. This includes a breakdown of the estimated system LCOE for different combinations of onshore/offshore solar PV and wind.

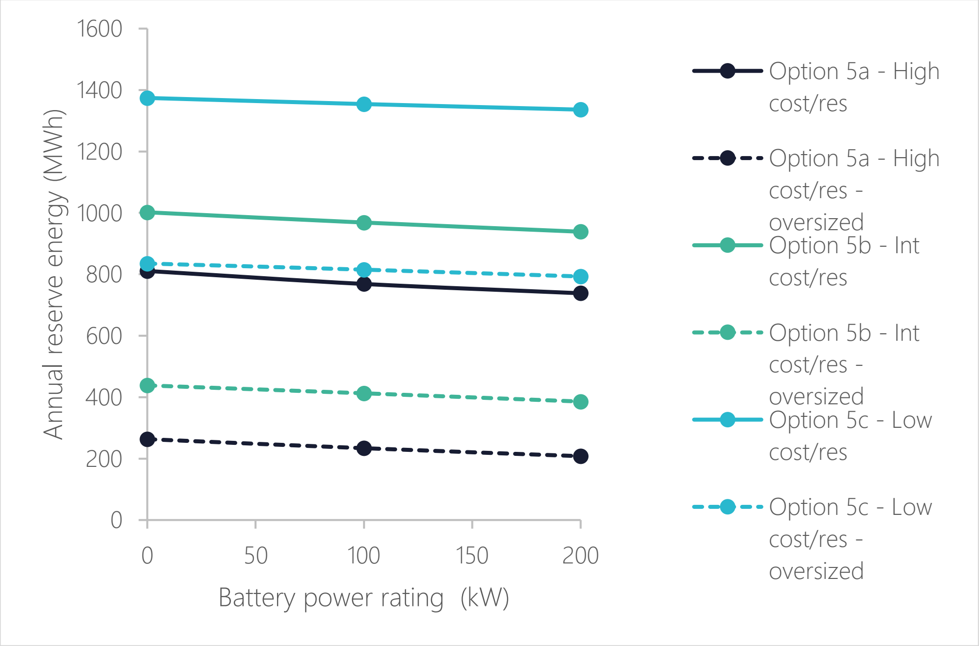


Figure 6-57. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 5, with and without renewable generation oversizing.

Recommendations

As with Scenarios 3 and 4, the main recommendations for Scenario 5 are reserved for after a business case analysis to fully assess the impacts of adopting wave power capacity within the renewable supply mix. Instead, recommendations here are kept general to comment on general trends that are likely to dictate the suitability of each system design.

Option 5c maintains a relatively low system LCOE of around $A220/MWh, using 125kW of wave energy capacity. As with Scenario 4, the availability of a wave device with this nameplate power rating is an area that requires further investigation but is getting closer to devices being currently deployed (250kW). This is especially the case when oversizing renewables, so that 187kW of wave capacity is installed. In Option 5c oversizing of renewable generation results in a fairly modest increase in system LCOE of 8%, and a 38% reduction in reserve energy requirement.

7 MARKETPLACE PRE-FEASIBILITY STUDY OUTCOMES

This technical feasibility study has assessed a wide range of technical and corresponding economic factors that are required to understand the value of any early-stage project. These assessments have provided important insights and outcomes that clarify the practical implementation of an integrated energy system for the Marketplace and will support an evidence-based discussion for AOEG as it seeks to mature the project concept.

The renewable resource assessment identified the renewable potential from both ocean and land-based resources across a variety of granularity levels, including annual, seasonal, monthly and hourly variations. This will allow the Marketplace to narrow its focus to solar, wind and wave energy as the most suitable renewable supply options moving forward.

The electricity demand scenario assessment has allowed AOEG to consider the level of impact the Marketplace could have to both already identified community members, such as its foundational partner, Discovery Bay, but also adjacent local businesses that face similar energy security challenges. Scenario Phase 2 was selected as the demand base case and has formed the basis of a Minimum Viable Product (MVP) approach. This focussed the Marketplace on the core needs of AOEG and Discovery Bay. However, through this assessment, AOEG have recognised adjacent demand centres as future options to scale up the Marketplace to meet additional community needs, where appropriate.

Energy system modelling undertaken has provided a variety of combinations of suitable renewable resources that are able to meet the identified demand of the Marketplace. Each scenario explores supply options depending on low cost or resilience preferences. This, coupled with potential battery storage allowed each system to be optimised to ensure demand could be met regardless of the timing of renewable energy dispatch. An intermediate cost to resilience energy system of 28.5kW solar, 17kW wind, 5.5kW wave and 30MWh of battery storage was selected as the Minimum Viable Product (MVP) to meet demand scenario phase 2. This assessment provides AOEG with a robust portfolio of supply options to decide what is most appropriate for the Marketplace

Using existing research published by NREL, the capital cost required to develop this base case energy system was estimated to be approximately A$574,993, including contingencies. Given the early-stage assessment of the Marketplace, these estimates are +/- 40% accuracy. Preliminary revenue options were developed based on AOEG’s planned Marketplace business offerings. System economics were modelled by combining cost and revenue aspects of the Marketplace. This resulted in a pre-tax Net Present Value of ~A$1.6 million.

These assessments have identified that there is clear value for the energy system that supports the Marketplace. However, it should be reiterated that the Marketplace concept remains in the early stages of its development roadmap, as detailed in Figure 7-1. For the Marketplace to move toward value realisation, it is recommended that further studies are undertaken to build on these technical feasibility outcomes. Commissioning a field assessment of renewable resources will validate the desktop findings of this study. The current public dataset used lacks the granularity and completeness required to make confident decision on energy system design. Following the outcomes of an improved resource assessment, the detailed design of the generation system will be required.

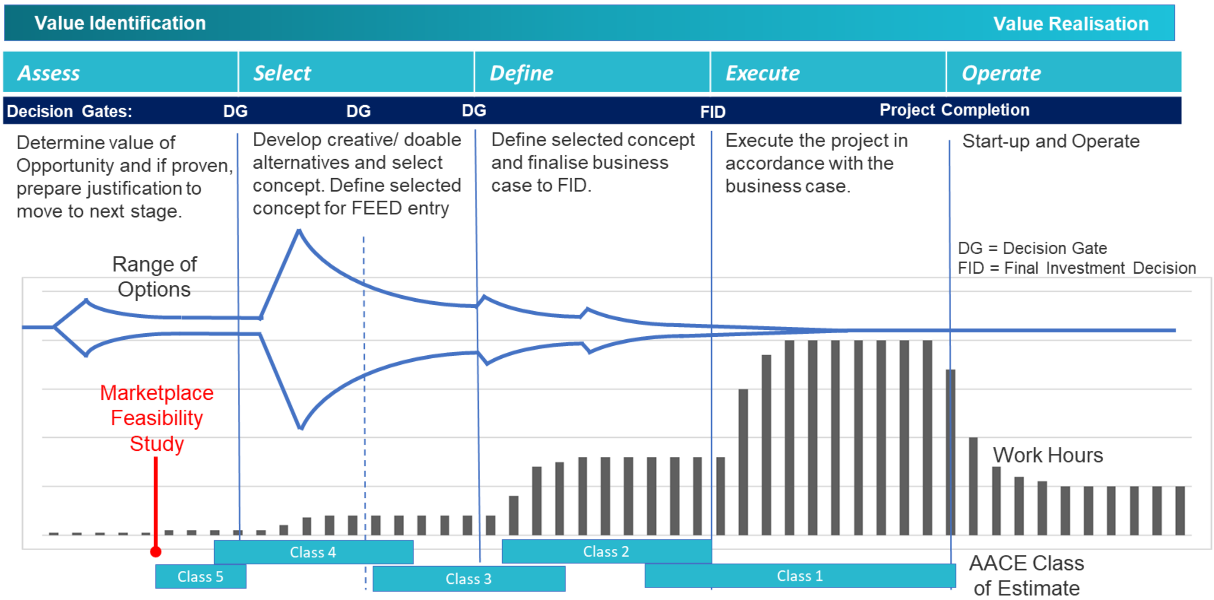


Figure 7-1 General Project Development Roadmap

7.1 Summary of Recommendations:

1. It is recommended that AOEG should conduct a definitive resource assessment to obtain a complete and granular dataset to increase the confidence of the identified resource potential.
2. Undertaking the detailed design of the Marketplace microgrid will be required to gain a bankable cost estimate and provide greater confidence in the Marketplace concept as it matures towards a Final Investment Decision (FID). These two assessments are critical for the Marketplace to develop a robust and clear development pathway.
3. Mapping businesses and agencies in the region requiring energy, including those carrying out water desalination and wastewater treatment and aggregating their demand would help quantify the market potential – this is currently out of the scope of this study but could be considered in the future.
4. This report provides the foundations on which AOEG may build a robust business model and strong commercial partnerships further down the development path for additional revenue options such as the Professional Services and Ocean Energy Training Centre.
5. Based on the gravity of local impact the Marketplace can deliver to Discovery Bay and Albany region, AOEG should consider local funding proponents. As electricity network reforms are immanent, Synergy and Western Power should be two candidates for funding. Synergy, a Western Australian government-owned utility has been granted A$3.8 billion in government funding to invest into green power infrastructure by 2030, to enable network reforms.
6. The City of Albany should be considered as another funding candidate. As the Marketplace addresses decarbonisation and represents first steps to improving energy access in communities and building a new industry, potential grants to fund further studies may be considered.

APPENDIX A SCENARIOS 1 TO 5 – ENERGY SYSTEM MODELLING RESULTS

Table A 1. Summary of all Scenario 1 Energy System Modelling Results.

Scenario	Solar PV capacity (kW)	Wind capacity (kW)	Wave capacity (kW)	Energy storage capacity (kW)	Reserve energy (MWh)	LCoE: Ons sol, Ons win	LCoE: Off sol, Ons win	LCoE: Ons sol, Off win	LCoE: Off sol, Off win
No oversizing									
High cost/res	60	12	45	0	61	474	493	523	541
	60	12	45	25	57	463	479	512	528
	60	12	45	50	51	469	486	518	535
Low cost/res	36	48	0	0	81	277	288	462	473
	36	48	0	25	78	265	275	452	462
	36	48	0	50	74	268	278	456	466
Int cost/res	60	24	25	0	62	372	391	467	486
	60	24	25	25	58	358	375	456	472
	60	24	25	50	52	364	381	462	479
50% oversizing									
High cost/res	90	18	67.5	0	24	571	597	636	662
	90	18	67.5	25	19	562	585	627	651
	90	18	67.5	50	15	567	592	632	657
Low cost/res	54	72	0	0	42	297	313	535	551
	54	72	0	25	39	290	304	532	547
	54	72	0	50	36	296	311	537	552
Int cost/res	90	36	37.5	0	25	436	462	561	587
	90	36	37.5	25	21	428	452	555	578
	90	36	37.5	50	16	431	456	557	582

Table A 2. Summary of all Scenario 2 Energy System Modelling Results.

Scenario	Solar PV capacity (kW)	Wind capacity (kW)	Wave capacity (kW)	Energy storage capacity (kW)	Reserve energy (MWh)	LCoE: Ons sol, Ons win	LCoE: Off sol, Ons win	LCoE: Ons sol, Off win	LCoE: Off sol, Off win
No oversizing									
High cost/res	60	12	55	0	60	499	516	547	564
	60	12	55	25	48	491	508	539	556
	60	12	55	50	41	492	508	540	556
Low cost/res	48	48	0	0	74	249	263	432	446
	48	48	0	25	66	245	258	429	442
	48	48	0	50	61	252	266	437	450
Int cost/res	60	36	10	0	64	297	315	437	454
	60	36	10	25	54	291	307	432	448
	60	36	10	50	49	297	314	438	454
50% oversizing									
High cost/res	90	18	82.5	0	22	603	628	667	692
	90	18	82.5	25	12	599	622	662	685
	90	18	82.5	50	8	604	628	667	691
Low cost/res	72	72	0	0	36	264	284	497	518
	72	72	0	25	29	265	284	499	519
	72	72	0	50	26	273	292	506	526
Int cost/res	90	54	15	0	27	337	362	516	541
	90	54	15	25	19	335	359	514	538
	90	54	15	50	15	342	366	519	543

Table A 3. Summary of all Scenario 3 Energy System Modelling Results.

Scenario	Solar PV capacity (kW)	Wind capacity (kW)	Wave capacity (kW)	Energy storage capacity (kW)	Reserve energy (MWh)	LCoE: Ons sol, Ons win	LCoE: Off sol, Ons win	LCoE: Ons sol, Off win	LCoE: Off sol, Off win
No oversizing									
High cost/res	300	300	700	0	439	557	563	657	663
	300	300	700	80	410	550	556	649	655
	300	300	700	160	394	552	558	651	657
Low cost/res	450	600	85	0	693	255	263	429	437
	450	600	85	80	673	252	260	425	433
	450	600	85	160	658	255	263	428	436
Int cost/res	300	450	450	0	528	436	442	576	582
	300	450	450	80	508	433	439	572	578
	300	450	450	160	495	435	441	575	581
50% oversizing									
High cost/res	450	450	1050	0	140	707	715	838	846
	450	450	1050	80	118	691	699	820	828
	450	450	1050	160	103	704	712	833	841
Low cost/res	675	900	127.5	0	418	292	303	516	527
	675	900	127.5	80	399	284	295	503	513
	675	900	127.5	160	379	292	302	513	524
Int cost/res	450	675	675	0	209	545	553	726	734
	450	675	675	80	189	534	542	712	720
	450	675	675	160	174	544	552	723	731

Table A 4. Summary of all Scenario 4 Energy System Modelling Results.

Scenario	Solar PV capacity (kW)	Wind capacity (kW)	Wave capacity (kW)	Energy storage capacity (kW)	Reserve energy (MWh)	LCoE: Onshore solar, Onshore wind	LCoE: Offshore solar, Onshore wind	LCoE: Onshore solar, Offshore wind	LCoE: Offshore solar, Offshore wind
No oversizing									
High cost/res	150	300	780	0	440	609	612	711	715
	150	300	780	80	414	602	605	703	706
	150	300	780	160	400	605	608	706	709
Low cost/res	450	600	45	0	719	240	248	418	426
	450	600	45	80	697	237	246	414	422
	450	600	45	160	680	240	248	417	425
Int cost/res	450	450	300	0	599	365	373	509	517
	450	450	300	80	573	361	369	503	511
	450	450	300	160	553	363	371	505	513
50% oversizing									
High cost/res	225	450	1170	0	137	774	778	908	912
	225	450	1170	80	116	753	758	884	888
	225	450	1170	160	103	769	774	902	906
Low cost/res	675	900	67.5	0	459	270	281	500	511
	675	900	67.5	80	439	262	273	486	497
	675	900	67.5	160	418	270	280	497	507
Int cost/res	675	675	450	0	305	448	458	636	646
	675	675	450	80	286	434	444	616	627
	675	675	450	160	265	446	456	631	642

Table A 5. Summary of all Scenario 5 Energy System Modelling Results.

Scenario	Solar PV capacity (kW)	Wind capacity (kW)	Wave capacity (kW)	Energy storage capacity (kW)	Reserve energy (MWh)	LCoE: Onshore solar, Onshore wind	LCoE: Offshore solar, Onshore wind	LCoE: Onshore solar, Offshore wind	LCoE: Offshore solar, Offshore wind
No oversizing									
High cost/res	500	500	1400	0	811	581	586	667	672
	500	500	1400	100	769	570	575	654	659
	500	500	1400	200	738	574	578	658	663
Low cost/res	500	1250	125	0	1374	223	228	372	377
	500	1250	125	100	1354	220	224	367	371
	500	1250	125	200	1336	224	228	372	376
Int cost/res	750	750	780	0	1002	408	414	523	529
	750	750	780	100	969	402	407	515	521
	750	750	780	200	939	405	411	519	525
50% oversizing									
High cost/res	750	750	2100	0	263	738	745	851	858
	750	750	2100	100	234	707	713	815	821
	750	750	2100	200	208	726	733	837	843
Low cost/res	750	1875	187.5	0	835	248	254	438	444
	750	1875	187.5	100	815	237	243	422	428
	750	1875	187.5	200	793	246	252	434	441
Int cost/res	1125	1125	1170	0	438	510	517	660	667
	1125	1125	1170	100	413	485	493	630	637
	1125	1125	1170	200	386	503	510	651	658

APPENDIX B POTENTIAL REVENUE ASSESSMENT

B.1 Methodology and Revenue Themes

A workshop was conducted by the project team which included discussion of potential revenue streams for the Marketplace.

This section describes the main ideas generated and recommended for detailed analysis in the business/operations plan.

B.1.1 Revenue Considerations

The identified areas of revenue were grouped under the themes of government and impact fund grants, enhancing the tourism proposition, consultancy, training and energy related services.

Industry Grants
A grant is a sum of money given by a government or other organisation for a particular purpose so the Marketplace project could apply for government or agency grants intended for capital equipment acquisition (CAPEX) or running costs (OPEX) if available for renewable technologies deployment, use or education. Available funding may be limited to a particular energy supply or use (e.g. community EV or device charging, STEM, etc.) rather than for the entirety of the Marketplace. While listed first, the size of the grant would be calculated last after the economic modelling of other potential revenues. Another consideration will be the governance structure of the Marketplace. Grants are normally distributed to not-for-profit organisations. If the Marketplace governance is a for-profit enterprise, grants may be limited.

Marketplace Visitor Fee Improvements
Discovery Bay is an existing and thriving tourism site, that offers historical and educational experiences to its wide variety of visitors. Typically, the tourism site welcomes 55,000 visitors per year. Further information on Discovery Bay's history and visitation is detailed in Section 3.2. The integration of the Marketplace to the Discovery Bay experience would enhance the tourism selling points as well as promote a forward-looking industry and different interest topics. This should contribute significant revenue diversification and growth for Discovery Bay's business ventures., meeting a key objective of their participation in the Marketplace.

Naming Rights

Naming rights are offered by entities such as the Australian National Maritime Museum. In exchange the buyer gets a marketing property to promote products and services, promote customer retention and/or increase market share.

Naming rights would require negotiation with a potential sponsor on duration, committed funding and/or revenue streams.

Professional Services

On-site professional services and training activities is another revenue avenue that AOEG could pursue. The creation of a physical space in Discovery Bay to host the Marketplace will provide office and workshop space. AOEG has considered providing services for market entities interested in pursuing knowledge and data on ocean energy potential, including project design, development and management support to prospective end-users intending to develop an ocean energy system.

Consenting and Secretariat services could also be added to the offering as it is done in other marine energy centres outside Australia. Note that any detailed technical work, such as energy yields, materials testing and design, and project development may be referred to an AOEG member or partner of choice. In respect of providing training, a unique proposition could be built around in person training given the important touristic location, access to the Marketplace control room, external activities such as site visits and boat trips to the offshore generation devices. This would appeal not only to Australian visitors from outside the city of Albany but also from international visitors and contribute to Marketplace being a regional hub. Once training was established, online delivery of certain components could be pursued.

Other training options include delivering STEM (science, technology, engineering and mathematics) activities to students and adults on behalf of energy developers, by the Marketplace or to establish hands-on workshops with donated energy generation equipment, which would require additional investment and specialised staff. This could be developed in partnership with UWA's Marine Energy Program and/or Discovery Bay's expanding educational programs.

Monetising Digital Data

The Marketplace is planning to integrate digital sensors onto the onshore and offshore energy generation devices to record energy generation performance and marine site data (wind speed, waves). This data could be sold to other marine energy developers and researchers utilising a digital interface. Lessons learned, blueprint and insights extracted by AOEG could enhance the quality of professional services that it intends to provide to the industry.

Electricity Offtake

Discovery Bay currently receives electricity via a single-phase overhead transmission line that connects to the South West Interconnected System (SWIS). Discovery Bay hires portable diesel generators to provide electricity to onsite facilities and maintain normal business operations when they are informed in advance of planned outages. As discussed in section 5.2, unplanned outages cannot be easily catered for currently, resulting in loss of revenues for Discovery Bay. Currently Discovery Bay is undertaking a cost benefit analysis of remaining on the grid and reviewing the potential to acquire electricity generated by the Marketplace. It could be economically advantageous to both parties to agree a unit price that is lower than the cost of energy incurred by Discovery Bay, with higher reliability and which covers at least the cost of operating and maintaining the generating devices.

Mapping neighbouring businesses and agencies in the region requiring energy could result in additional offtake routes with additional revenues and improved management of energy curtailment. This opportunity was not modelled in this study.

Renewable Energy Certificates Opportunities

Selling surplus energy to the grid requires maintaining of a connection to the SWIS which would allow bidirectional flow. This may be prevented if Discovery Bay removes its grid access in the future.

It could be possible to create and trade Renewable Energy Certificates (RECs) by the generated renewable electricity from the Marketplace. RECs are a commodity that is used to track and verify the production of renewable energy in Australia. Under the Renewable Energy (Electricity) Act 2000 (the "2000 Act"), two types of RECs exist in Australia, these being small-scale technology certificates (STCs) and large-scale generation certificates (LGCs). STCs are created in relation to the installation of solar water heaters and small generation units while LGCs are created in relation to the generation of electricity by accredited power stations. The Clean Energy Regulator is indicated as the regulatory entity under the 2000 Act.

Under Guidance of the Clean Energy Regulator [37], to be eligible for small-scale technology certificates, small generation units (including solar photovoltaic panels, wind turbines, and hydro systems) must be classified as small-scale, and be a:

- solar panel system that has a capacity of no more than 100 kW, and a total annual electricity output less than 250 MWh
- wind system that has a capacity of no more than 10 kW, and a total annual electricity output of less than 25 MWh, or
- hydro system that has a capacity of no more than 6.4 kW, and a total annual electricity output of less than 25 MWh.

Under the 2000 Act, RECs that can be created from small electricity generation units are limited to the energy generated by the first 3kW of installed capacity. This could be increased to the energy generated by the first 20kW of installed capacity if certain criteria to qualify as an off-grid small station was fulfilled although it could be argued this is not the case for new generation at Discovery Bay.

If a small-generation unit is larger than the capacity limits listed above, it will be classified as a power station and must be accredited as a power station under the Large-scale Renewable Energy Target. If accreditation is successful, the unit may be eligible for large-scale generation certificates which would not have caps like STCs do [38].

This would mean that there could be merit on modelling the creation of RECs of both types which could later be traded and monetised. Under the 2020 Act, no certificates can be created in respect of electricity generated on or after 1 January 2031.

Additional Marine Services Requiring Investment

In a subsequent phase and subject to actual demand being identified, shoreside infrastructure could be considered to welcome electric marine vessels supporting the developing aquaculture and tourism industries, selling parking and electricity to them as a battery refuelling service.

Additional investment would be required to provide an additional electrical connection offshore so that developers could install their devices and test them delivering electricity onshore. However, this would require additional offshore capex and changes to the electrical system so that it could take additional energy.

B.2 Business Plan Overview

The Marketplace has been assessed on its technical, merits with identification of corresponding business (revenue) opportunities at the proposed site in Discovery Bay, Albany. This techno-economic assessment identified a robust and diverse renewable energy resource that could be developed using technologies identified to meet the electricity needs of AOEG, Discovery Bay and adjacent current or future businesses.

The future business plan for the Marketplace will use the technical assessment described in the preceding sections as a foundation to assess the economic viability of the project. Economic viability will assess a selected demand scenario, the associated costs to develop and maintain the project, commercial opportunities based on AOEG's Marketplace business drivers and lastly, project funding considerations.

Implementing a sustainable use of ocean and marine resources will not only address the region's energy needs but will also combat climate change and make energy accessible and affordable to other communities and islands along the coast – specifically addressing SDGs 7, 13, and 14. To achieve these objectives, an enabling political and social environment will be required, as well as less complex regulatory and administrative processes.

In addition, the proposed Ocean Energy Marketplace would have non-economic benefits. These include educating policymakers about OE technologies, creating deployment and business model frameworks to encourage investments, grants, and funding to support fundamental research and development at various technological readiness levels, ranging from laboratory and demonstration to commercial scale.

B.3 Marketplace Roadmap: Demand Profile Utilised and Power Strategy

Concept Roadmap

The present study consolidated knowledge and assessed the opportunity to support normal and expanded business operations for Discovery Bay and the needs of the AOEG and the Marketplace. Figure B 7-1 illustrates the series of workplans undertaken throughout this study, as well as the various stakeholder workshops that have shaped and calibrated the approach to the Marketplace.

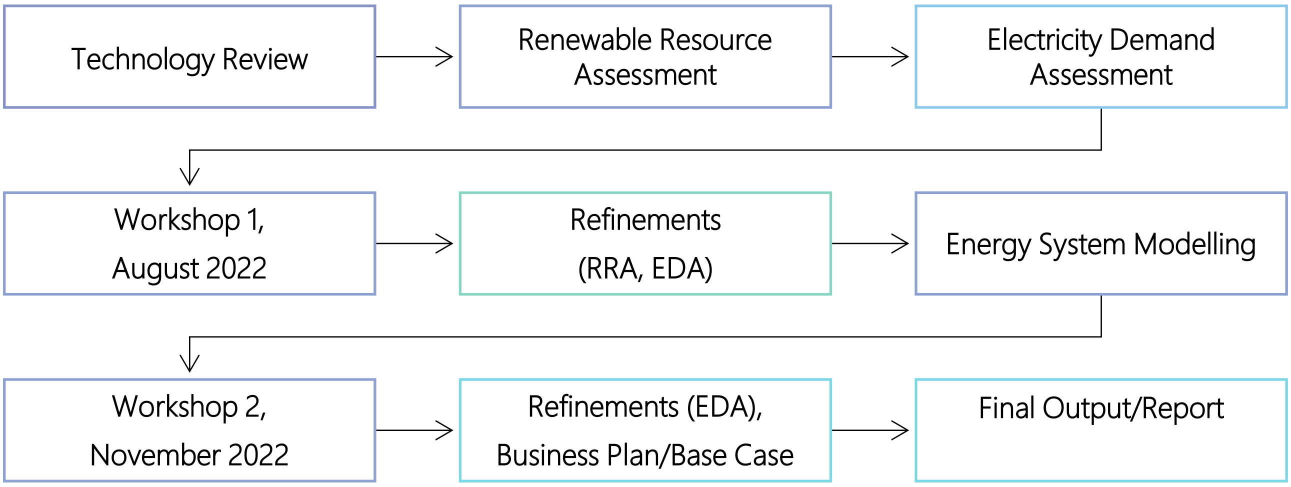


Figure B 7-1. Flowchart of work conducted during this study, including workshops.

As discussed in sections 6.4 and 6.5 for demand and energy system modelling methodology, five scenarios were developed with annual electricity demand ranging from 0.24 GWh to 5.71 GWh in alignment with AOEG. These allowed a variety of electricity supply and demand balances to be explored, modelled and discussed at both workshops.

At Workshop 2, the study team presented all scenarios and highlighted demand scenario 2 (0.26 GWh per year) as a potential base case for the Marketplace. Workshop delegates agreed to a number of revisions, for instance adding a modified version of scenario 2 (removing large-scale desalination as it required a disproportionate amount of energy and was not necessarily aligned with the objectives of AOEG or Discovery Bay at this point in time), which would be the focus of the business case. It was also agreed to develop a staged renewable energy implementation approach, as suggested by AOEG, recognising that Discovery Bay should proceed with solar and batteries in the short-term which could be integrated with Marketplace systems in the future.

The revised staged approach quantified a list of modified scenarios using different combinations of the same demand components. Demand for these scenarios was towards the lower end of the previous electricity demand range. Scenarios (labelled DB1 to DB2 and Phases 1 to 3, requiring from 0.11 to 0.23 GWh of demand per year) were designed as EV charging and large-scale desalination were removed (Scenario 1 minus EV charger, Scenario 2 minus EV charger, Scenario 4 minus large desalination). For the purposes of business plan, the Scenario Phase 2 (0.12 GWh per year) was used, which was derived from the initial Scenario 2 but excluding the EV charger. Table B 1 lists its components and the hourly demand profile of each component is shown in Figure B 7-2.

Table B 1. Phase 2 scenario - components of electricity demand (totalling 0.12 GWh per year).

COMPONENTS				
Amphitheatre	Cameras – land	Cameras - marine	Chargers – bike	Chargers - phone

COMPONENTS				
Control Room	Desal. small	Lighting	Offices (DB and AOEG)	Staging area
Water filtration & purification	Whaling Station, Museum & Cafe			

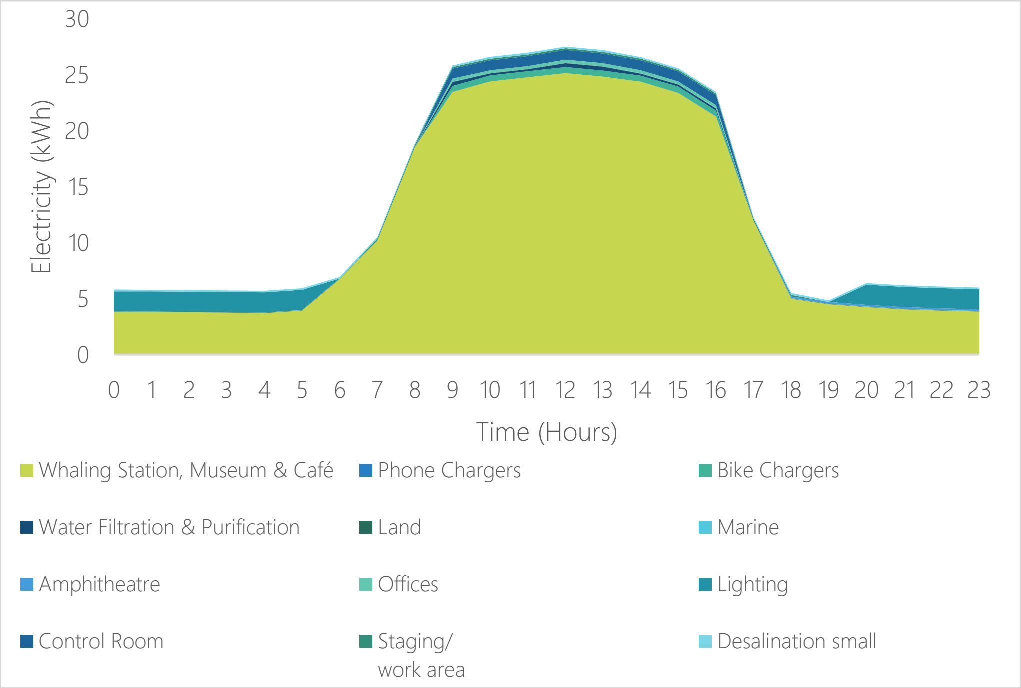


Figure B 7-2. Scenario Phase 2 – Hourly electricity demand profile.

As per the approach detailed in Section 6.6 Energy System Modelling Results, all supply and demand data has been modelled to ascertain the optimal combination of solar PV, wind and wave installed capacities to minimise the annual energy shortages, and in turn back-up or reserve electricity supply. Capacity factors applied to the installed capacities of solar, wind and wave energy were 18.6%, 42.24% and 24.8% were, respectively to derive energy generated per year. Table B 2 lists the installed capacity options. Phase 2a minimises the reliance on back-up supply, Phase 2b uses an intermediate level of wave power capacity and Phase 2c removes the use of wave energy.

Table B 2 Scenario Phase 2 – installed capacity and reliance on back-up supply – excluding battery use.

OPTION	SOLAR PV	WIND	WAVE	RESERVE ENERGY
Phase 2 a: High cost/resilience	28 kW	5.8 kW	25 kW	29 MWh
Phase 2 b: Intermediate cost/resilience	28.5 kW	17 kW	5.5 kW	30 MWh
Phase 2 c: Low cost/resilience	22.8 kW	22.8 kW	0 kW	35.5 MWh

The use of a battery for energy storage was explored in terms of its impact on surplus renewable energy available the required reserve energy – this is shown in Table B 3.

Table B 3 - Scenario Phase 2b – impact on surplus renewable and reserve energy from battery use.

BATTERY CAPACITY	SURPLUS RENEWABLE ENERGY	RESERVE ENERGY
0	30 MWh	30 MWh
12.5 kW	22 MWh	25 MWh
25 kW	21 MWh	23 MWh
37.5 kW	19 MWh	21 MWh
50 kW	17 MWh	19 MWh

B.4 Economic Model

B.4.1 Overview

An economic model for the energy system supporting the Marketplace and Discovery Bay was developed for the purpose of investigating the economic viability of the system by using the technical and commercial inputs identified throughout this study.

B.4.2 Model Assumptions

Assumptions have been made around timing of project development, commercial arrangements and further areas where knowledge gaps have existed. Table B 4 and Table B 5 summarise the key assumptions used in the economic model for inflation, discounting and timing of expenditures and electricity generation.

Table B 4. Assumptions used in the Marketplace economic model.

ECONOMIC VARIABLE	ASSUMPTION	COST VARIABLE	ASSUMPTION
Inflation	2% (from 2023)	Construction commencement	2025
Discount Rate	7% (to 2023)	Duration of Construction	2 yrs
FX AUD/USD	1.52	Operational Start Date	2027
Project Life	25 years		
Project End Date	2051		

Table B 5. Asset lives for renewable energy generation assets.

GENERATION ASSET	ENERGY TYPE	USEFUL LIFE (YEARS)
Asset life Wave Energy Converter	Wave	21
Asset life Solar Panels	Solar	25
Asset life Battery	Battery Storage	7
Asset life Wind Energy	Wind	25

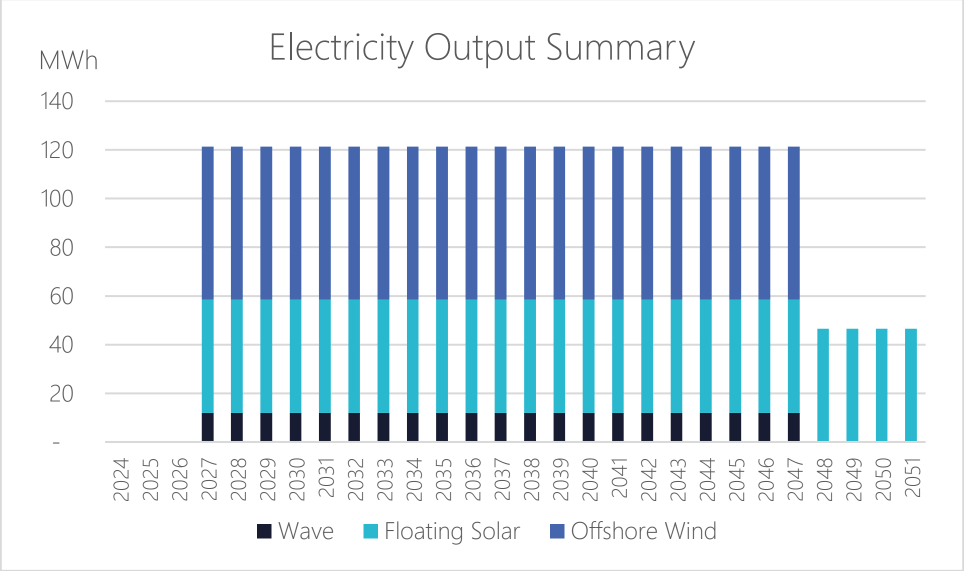


Figure B 7-3. Generation profile based on useful life of generation asset.

B.4.3 Cost Profiles

Cost estimates for building the required generation capacity for the Scenario Phase 2b energy system has followed the same methodology described in Section 6.5.1. Phase 2b proposes an energy system comprising of a combined installed capacity for wave, offshore solar and wind energy of 51 kW. Table B 6**Error! Reference source not found.** illustrates the Total Installation Costs (TIC) per kilowatt for wave, floating solar and offshore wind installed capacity.

As detailed in Section 6.5.1, TIC used for wave and offshore wind is notably higher than CSIRO GenCost estimates. The decision to implement higher costs was based on existing research by NREL on cost estimates for the installation of smaller generation capacities, similar to those proposed for the Marketplace. Furthermore, floating solar is not included in the CSIRO GenCost estimates, therefore NREL guidance was used.

In order to determine the CAPEX and OPEX for the proposed battery system, the Annual Technology Baseline for Commercial Battery Storage tool provided by the National Renewable Energy Laboratory (NREL) was implemented [39]. The Capex unit price was chosen as an average between the conservative and moderate scenarios provided by the tool, which was determined to be A$ 1,583/kW in 2026. Additionally, a fixed OPEX price per year was determined using the tool, which was determined to be $ 39.6/kW-year..

It was assumed that the battery system would have a capacity to provide electricity for 2 hours and that the batteries in the system would need to be replaced every 7 years. This results in additional CAPEX costs in the years 2026, 2033, and 2040. The total CAPEX for the battery system was A$108,235 and annual average OPEX was calculated to be A$861, not adjusted for inflation.

Table B 6. Cost estimate comparison.

Phase 2 b	Installed Capacity (kW)	TIC Price per kW (A$ 2022)	CSIRO 21-22 GenCost A$/kW (2022)	CSIRO 22-23 GenCost A$/kW (2022)
Wave	5.5	15,500	9,745	11,662
Floating Solar	28.5	2,223	N/A	N/A
Offshore Wind	17	13,949	4,649	5,682

As a result, the total capital expenditure (CAPEX) estimated to build out installed generation capacity and battery storage for the Marketplace is A$574,993. This estimate has been given a +/- 40% accuracy range to reflect the preliminary and incomplete data used. This is inclusive of contingencies and insurance but does not account for inflation. A further breakdown of CAPEX by generation type is detailed in Table B 7.

Table B 7. Scenario Phase 2 estimated CAPEX and OPEX by installed renewable generation capacity, unadjusted for inflation.

Renewable Generation Type	Installed Capacity kW	Capex Low (-40%) A$ 2022	Capex A$ 2022	Capex High (+40%) A$ 2022	Annual Opex A$ 2022
Wave	5.5	61,892	103,153	144,414	2,063
Floating Solar	28.5	46,006	76,676	107,346	2,300
Offshore Wind	17	172,157	286,929	401,700	8,608
Battery Storage	25	64,941	108,235	151,529	861
Total	76	344,996	574,993	804,990	13,832

Annual operating costs for the installed generation capacity is estimated at A$13,832 (unadjusted for inflation) assuming all devices are located offshore, except for battery storage. No estimate has been built for the construction of the Marketplace premises.

Figure B *7-4* illustrates a two-year construction timeline for the Marketplace by generation to be installed. New installation of battery storage will be required every 7 years, due to the expected useful life of 7 years. The cost curve for battery storage is expected to decline over future years, however it has not been factored into the current economic modelling.

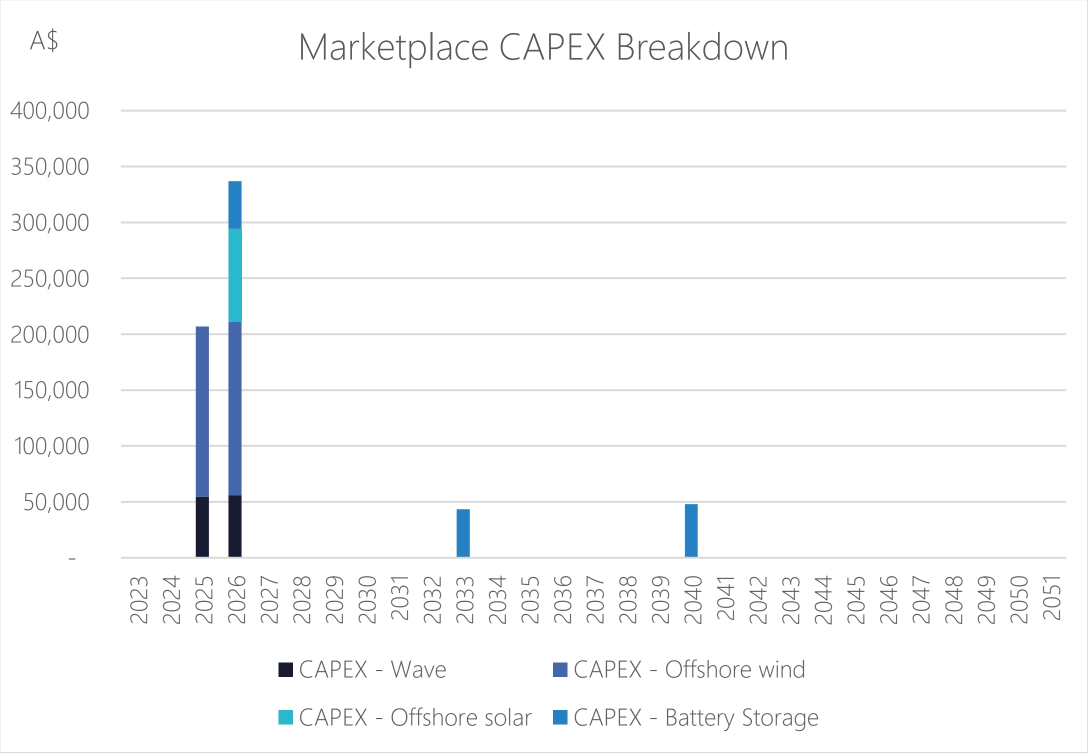


Figure B 7-4. Distribution of CAPEX by generation type to be installed (Adjusted for inflation).

B.4.4 Marketplace Proposed Revenue

Six sources of revenue were integrated into the economic modelling for the Marketplace (see Figure B 7-5).

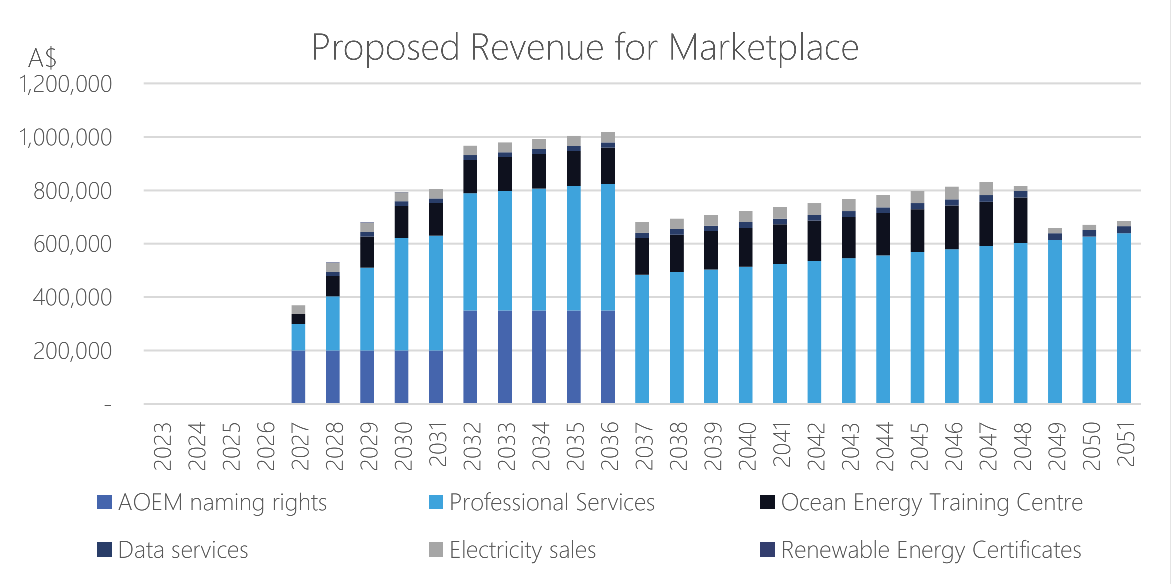


Figure B 7-5. Forecasted gross revenue for the marketplace, adjusted for inflation.

Marketplace Naming Rights

An initial sponsorship contractual worth in total A$1 million, split over 5 years, was modelled. A follow-on contract, worth a total A$1.75 million over another 5 years was also modelled. Costs associated with this revenue would be part of the Marketplace marketing costs.

Professional Services

It is assumed that AOEG would build a professional services business over the first 4 years of the Marketplace being in operation. This revenue stream would undertake four projects a year from 2030 onwards.

Two of these projects would be work scopes resulting in A$150,000 (before adjusting for inflation) of revenue per project, and the other two would generate A$30,000 (before adjusting for inflation) per project. In total, the professional services business would generate annual revenue of A$360,000 and total A$8.4 million (unadjusted for inflation) over the 25-year life of the Marketplace. Within the first 4 years of the Marketplace operating, smaller work scopes have been assumed to be undertaken, which also contributes to revenue.

Profitability of the professional service business has been assumed to make a 10% margin on all projects completed.

Ocean Energy Training Centre

It was assumed that AOEG will establish an Ocean Energy Training Centre within the Marketplace. This will offer training sessions from 2027, reaching its full capacity by the year 2029. The centre will offer training sessions once every two months. Training sessions are estimated to generate $17,000, totalling A$102,000 per year and generating ~A$2.2 million over the 21-year project life of the Marketplace.

Data Services

It was assumed that the revenue per data purchase is A$400, based on a reduction (due to measuring in only one site) of the prices of wind and marine ocean data available on the Datarad website, a global open market for data. The projected number of data purchases per month was assumed to be 3 and could start from the second year of operations. Utilizing these assumptions, the annual revenue of A$14,400 with a total revenue over 25 years of A$345,600, not adjusted for inflation.

Electricity Sales

The revenue generated from the sale of electricity is based on the assumption that only 100 MWh/year (82.64%) of the total electricity generation (121 MWh/year) will be provided to Discovery Bay at a 10% cheaper price than the unit price of the grid operator, while 21 MWh (17.36%) of surplus electricity will be provided to the grid at full price without any discount. According to the Australian Government wholesale electricity statistics, the wholesale price of grid electricity in Q3 2022 was 265 A$/MWh. With this assumption, the annual revenue averages A$26,579.9 with a total revenue over 25 years of A$664,497.10, not adjusted for inflation. It should be noted that revenues from electricity sales reduces towards the end of the Marketplace asset life due to some generation assets reaching the end of their useful life earlier than others. This is illustrated in Figure B 7-5. The above approach towards modelling will need to be discussed with Discovery Bay.

Renewable Energy Certificates

The calculated solar energy generation capacity would be eligible for STCs while the proposed wind and wave energy capacity would be eligible for LGCs if the installed plant was registered as power station (subject to final decisions on the Marketplace).

Revenue from STCs is limited to the first 3 kW of installed solar capacity. This revenue has been assumed from 2027 to 2030 – as specified in the 2020 Act – and being realised the year after the generation of electricity at a price of 35 A$/MWh. This price level assumes than future STC prices will be lower than the weighted average weekly STC price between 2017 and 2022 depicted in Figure B *7-6*, but will continue to decline at a slower rate than LGC prices (see Figure B *7-7*).

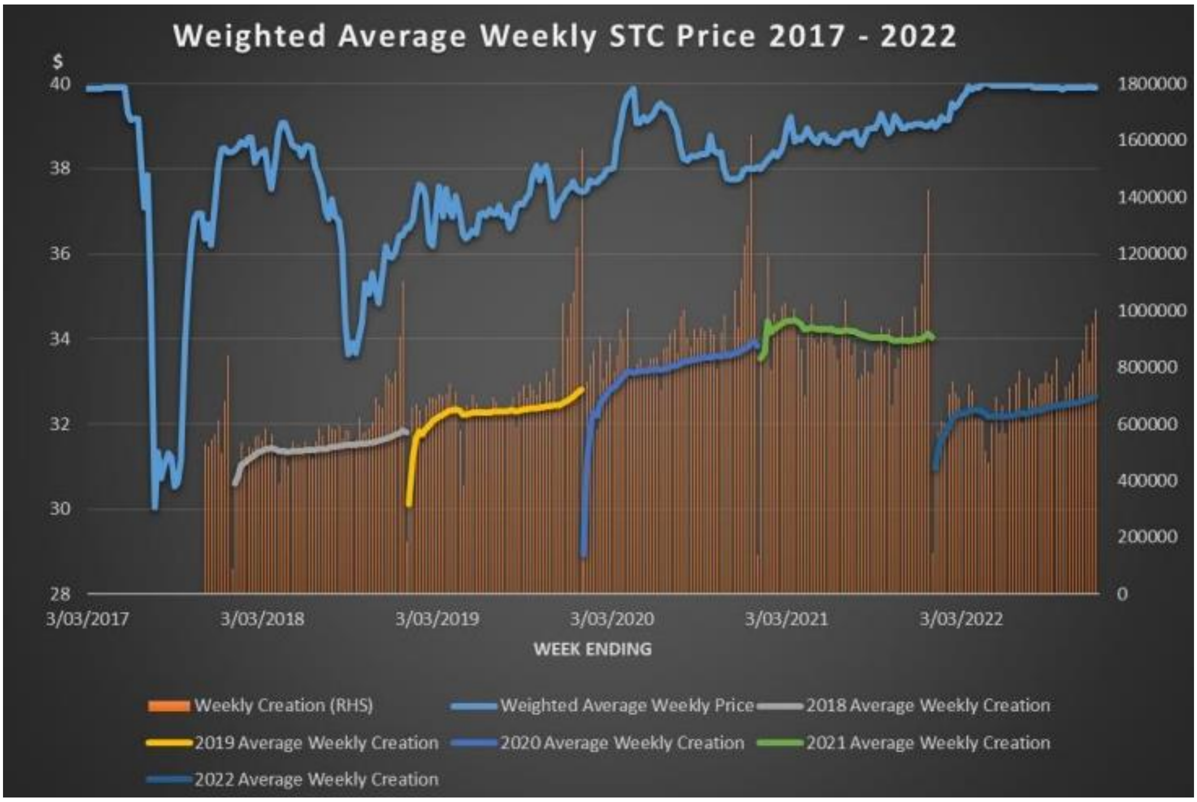


Figure B 7-6. Weighted average weekly STC price from 2017 to 2022.

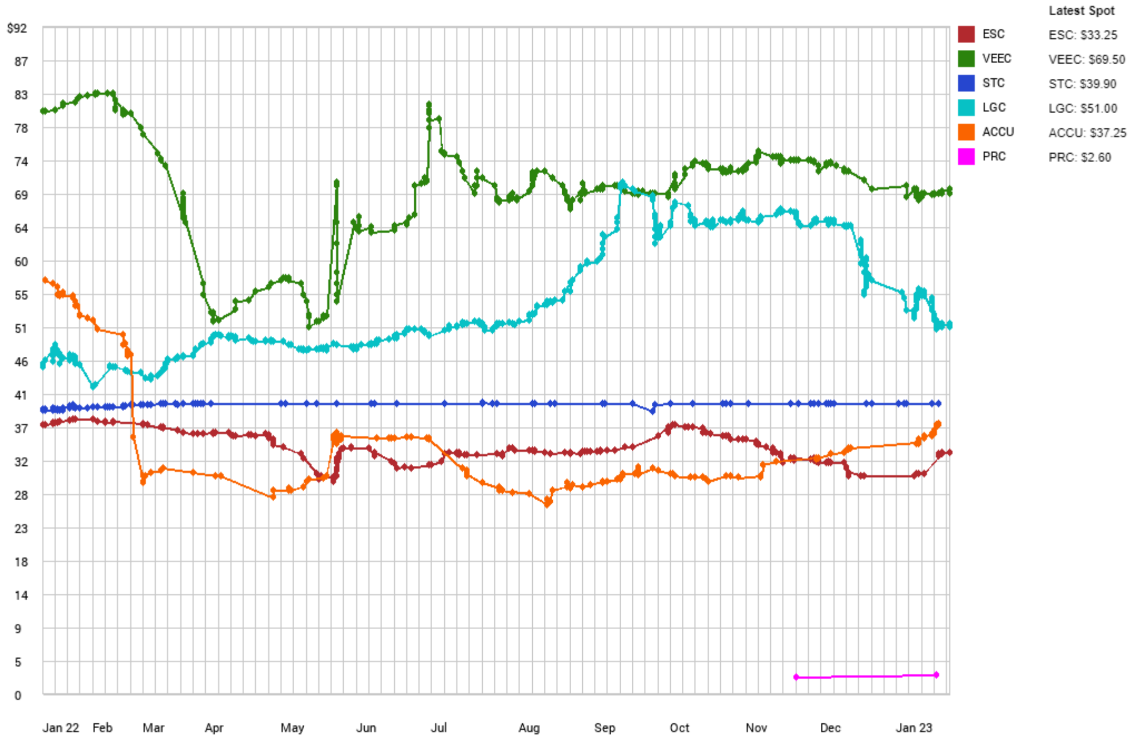
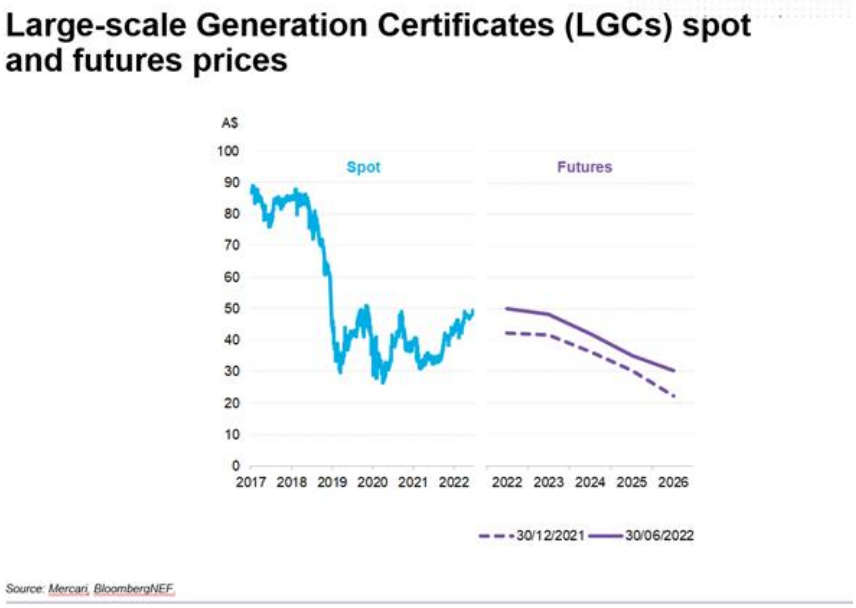


Figure B 7-7. Spot prices including those for STCs and LGCs [40].

Further clarifications are needed to understand if the Marketplace is eligible for LGCs. This would enable further revenue opportunities for surplus electricity generated from the Marketplace (see Figure B 7-8).



Source: Mercari, BloombergNEF

Figure B 7-8. Large-scale Generation Certificates (LGCs) spot and futures prices.

Revenue for LGCs arising from the 17.5 kW of wind energy capacity and 5.5 kW of wave energy capacity was calculated from 2027 to 2030 and being realised the year after the generation of electricity at a price of 30 A$/MWh.

Utilizing these assumptions, the annual revenue of A$1,181 with a total revenue over 4 years of A$4,725, not adjusted for inflation.

B.5 Cashflow Analysis

B.5.1 Overview

The Marketplace presents a robust economic business case based on the revenue, cost and scheduling assumptions discussed in the preceding sections of the business plan. Economic modelling outcomes highlight the Marketplace can generate an annual pre-tax net cashflow over A$200,000 from year one until year 9 (2036) of the project life and is expected to peak at ~A$428,000 in that year, as illustrated in Figure B 7-9 and Figure B 7-10. Based on these cashflows, the Marketplace has a Net Present Value of approximately A$ 1.6 million at a 7% discount rate.

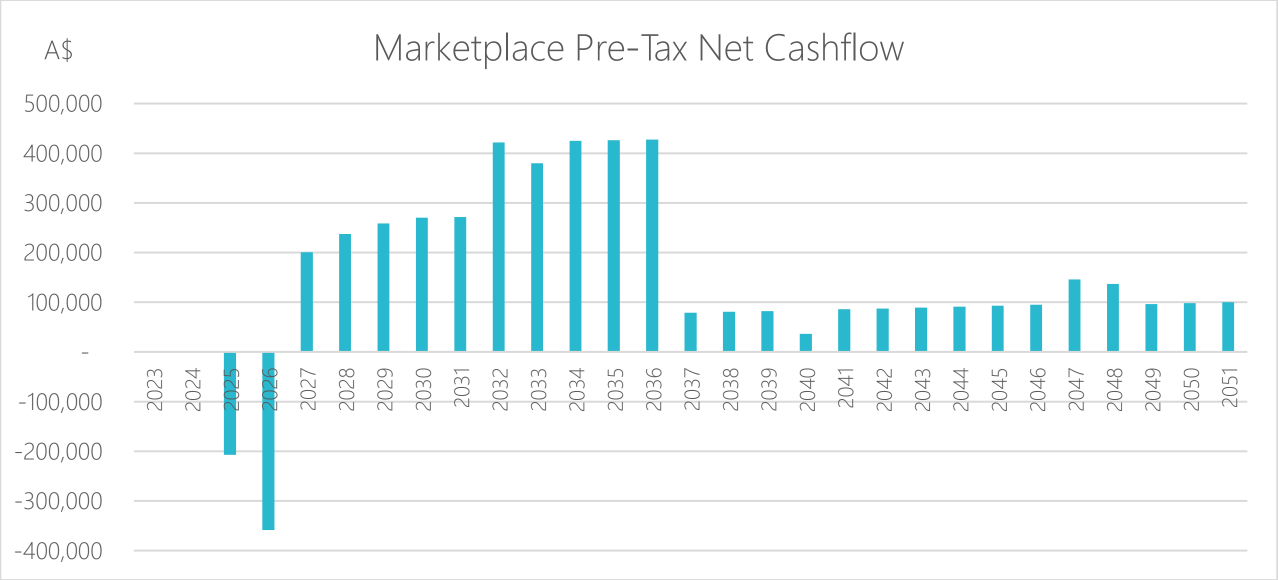


Figure B 7-9. Forecasted Pre-Tax Cashflow for the Marketplace.

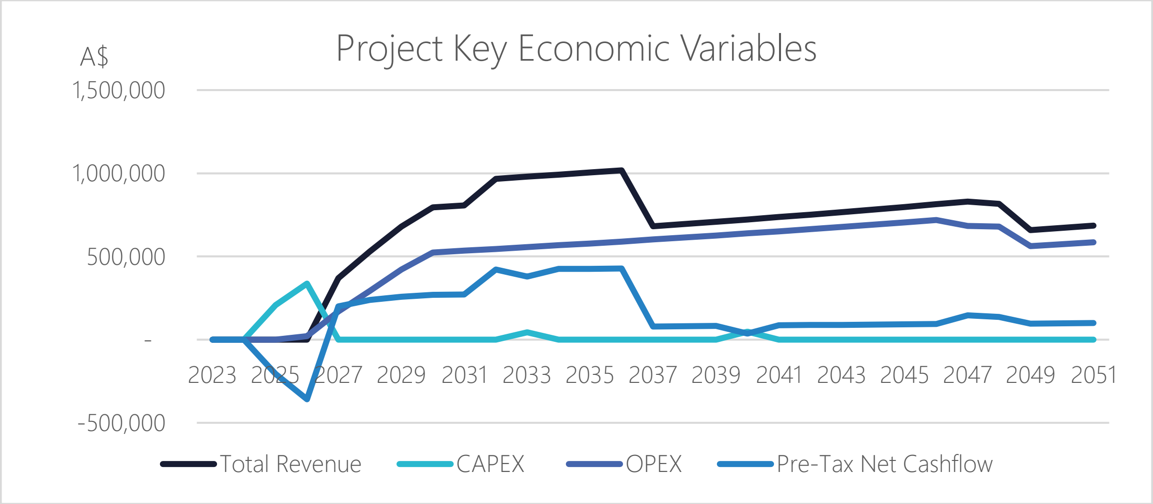


Figure B 7-10. Marketplace key economic variables.

B.5.2 8.4.2 Cashflow Risk Considerations

As highlighted earlier, a number of high-level assumptions have been made in terms of revenue options. Currently no commercial agreements are tied to the proposed Marketplace revenues identified in this assessment, therefore the attractiveness of the Marketplace economics should be considered preliminary.

The revenue option to enter into an electricity sales agreement with Discovery Bay represents the most realistic revenue option at this current stage of project maturity. Figure B 7-11**Error! Reference source not found.** illustrates an alternative scenario testing the economic levers of the project. In this example, the Marketplace economics is tested on the provision that the project is solely developed as a renewable energy provider to Discovery Bay. As a result, revenue generated from the electricity sales agreement and associated small-scale technology certificates (a type of REC) are the only contributors to the Marketplace income. This results in an NPV of negative ~A$257,000 and fails to recoup the initial project capex.

This example illustrates the need for AOEG to build a robust business model and strong commercial partnerships further down the development path for additional revenue options such as the Professional Services and Ocean Energy Training Centre.

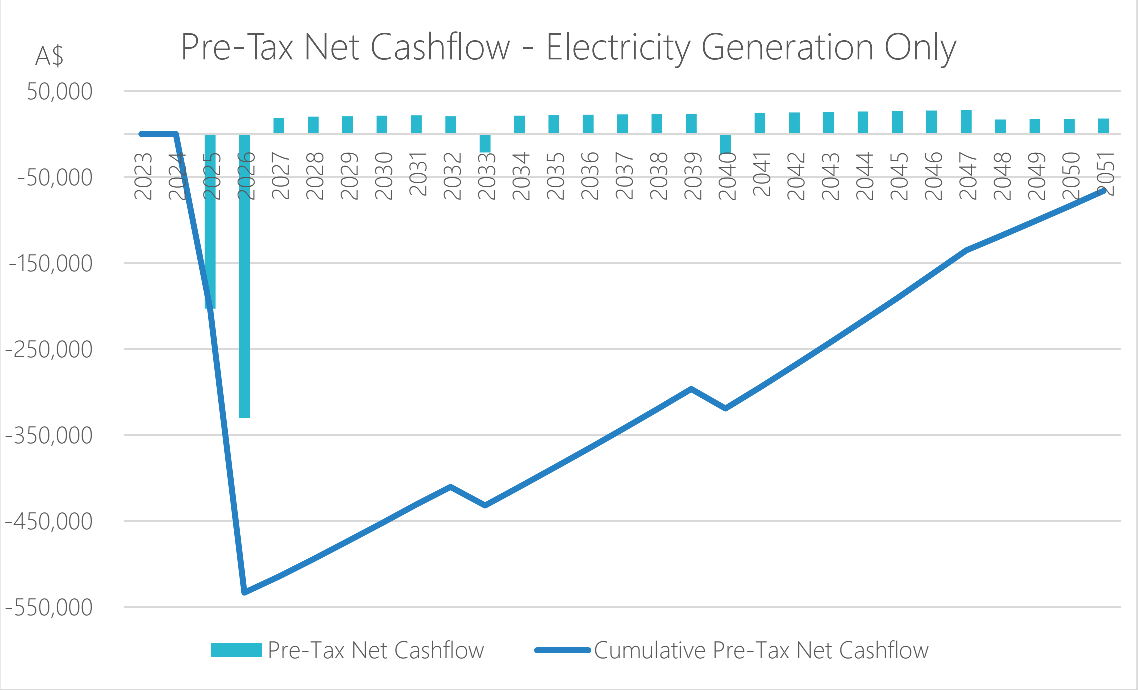


Figure B 7-11. Alternative marketplace Scenario testing project economics based on electricity generation only.

Another consideration for project economics is the discount rate applied to the Marketplace. This economic assessment has used a discount rate of 7%, however given the implementation of ocean energy and its largely new and emerging technology, this could represent further risks for funding options. As a result, a greater discount rate may need to be applied to reflect risk and return tolerance of creditors. Figure B 7-12 identifies the varying NPV outcomes based on different discount rates applied to the Marketplace economics.

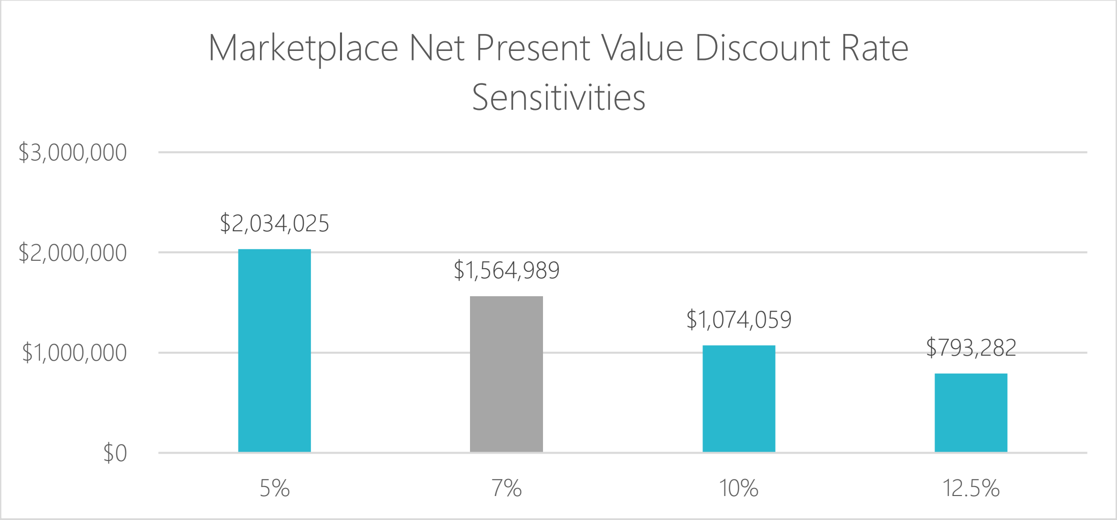


Figure B 7-12. Marketplace Net Present Value based on a range of discount rates.

B.5.3 Funding Considerations

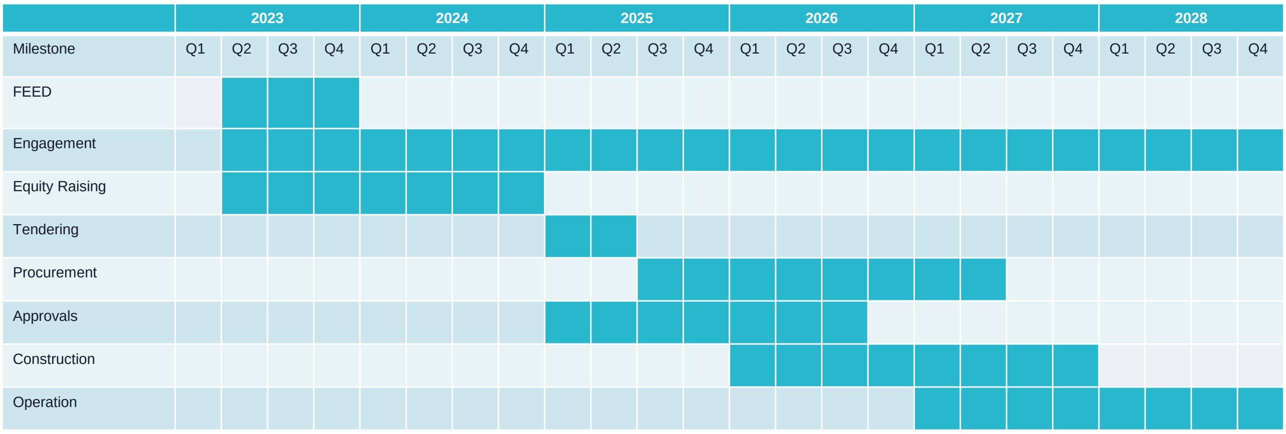
The Marketplace has the potential to have a significant impact on local community needs of both Discovery Bay and the adjacent Albany region, as well as broader impacts on the demonstration and accelerated adoption of ocean energy. However, large funding hurdles remain to realise project value. Further studies and comprehensive business/operational plan are required to move this project toward FID, as well as the current capital cost of A$574,993 to construct the Marketplace, which has been estimated within this study.

Based on the gravity of local impact the Marketplace can deliver to Discovery Bay and Albany region, AOEG should consider local funding proponents. As electricity network reforms are immanent, Synergy and Western Power should be two candidates for funding. Synergy, a Western Australian government-owned utility has been granted A$3.8 billion in government funding to invest into green power infrastructure by 2030, to enable network reforms.

The City of Albany should be considered as another funding candidate. As the Marketplace addresses decarbonisation and represents first steps to improving energy access in communities and building a new industry, potential grants to fund further studies may be considered.

B.6 Marketing

Figure B 7-13 shows an indicative project schedule for the Marketplace. AOEG should align the marketing process for the Marketplace with this timeline in order to meet a 2027 operational date.



	2023				2024				2025				2026				2027				2028			
Milestone	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
FEED		■	■	■																				
Engagement		■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■	■
Equity Raising		■	■	■	■	■	■	■																
Tendering									■	■														
Procurement											■	■	■	■	■	■	■	■						
Approvals									■	■	■	■	■	■	■									
Construction													■	■	■	■	■	■	■	■				
Operation																	■	■	■	■	■	■	■	■

Figure B 7-13. Sample steps on a marketing process for the Marketplace.

B.7 Marketplace Governance

The European Marine Energy Centre (EMEC) is an organisation based out of Scotland, focussing on marine energy research and its implementations and as such could provide guidance for the governance of the Marketplace. Currently EMEC has a governance structure including a board of directors, board observers, and multiple internal teams leading individual sectors within the business. The governance structure organogram can be seen in Figure B 7-14, demonstrating the governance structure used.

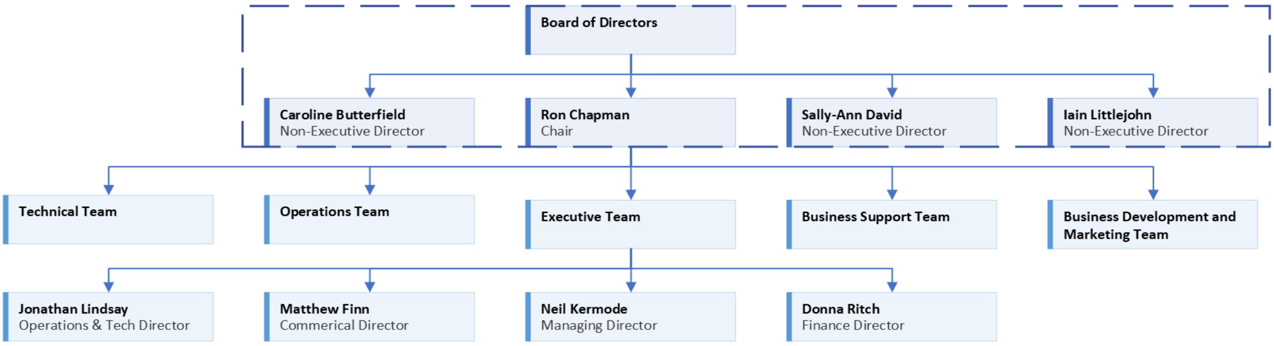


Figure B 7-14. Simplified EMEC Board Structure.

The board is further overseen by external board observers which include the Scottish Government, Local Council (Orkney Islands Council), and two enterprise support organisations – Scottish Enterprise and Highland & Islands Enterprise. These board observers fully work as formal members; however, they do not vote on formal matters and offer support and advice when and where required.

The three Non-Executive Directors included in the board hold a similar, but distinctly different, role to the board observers. Similarly, to the observers, they are not typically involved in the 'day-to-day' management of the organisation and still receive the full breadth of policy information. Where they differ to the observers is the access to a formal vote on decision making, regarding board-level policy and business decisions. The range of teams that exist below the board, run the 'day-to-day' work of the organisation – each with their own structure of management, heading by team leads. These mechanisms and structure of the business leads to an effective management of EMEC.

APPENDIX C REFERENCES

[1] Australian Renewable Energy Agency (ARENA), “Ocean Energy,” Australian Government, ARENA, 2023. [Online]. Available: https://arena.gov.au/renewable-energy/ocean/. [Accessed 09 Feb 2023].

[2] Australian Renewable Energy Agency (ARENA), “Projects (Ocean Energy),” Government of Australia, ARENA, 2023. [Online]. Available: https://arena.gov.au/projects/?project-value-start=0&project-value-end=200000000&technology=ocean. [Accessed 10 Jan 2023].

[3] Australian Goverment Department of Climate Change, Energy, the Environment and Water, “Australian Energy Statistics 2022,” 2022. [Online]. Available: https://www.energy.gov.au/publications/australian-energy-update-2022.

[4] Department of Climate Change, Energy, the Environment and Water, “Electricity Generation Data,” 2021. [Online]. Available: https://www.energy.gov.au/data/electricity-generation.

[5] Western Power, “The Future of the Grid,” Western Power, 2019. [Online]. Available: https://www.westernpower.com.au/community/news-opinion/the-future-of-the-grid-what-is-it-made-up-of/.

[6] Western Power, “Network Capacity Mapping Tool,” Western Power, [Online]. Available: https://westernpower.maps.arcgis.com/apps/webappviewer/index.html?id=21af5edc59034456b59c35be31365cdf.

[7] AEMO, “Wholesale Electricity Market Data Dashboard,” 2022.

[8] Infrastructure Australia, “Regional Strengths and Infrastructure Gaps; Regional Analysis, Western Australia.,” Government of Australia, Canberra, 2022.

[9] A. Bleicher and A. Pehlken, “The Material Basis of Energy Transitions,” London, Academic Press, 2020, p. 50.

[10] Australian Renewable Energy Agency (ARENA), “Technology Readiness Levels,” Australian Government, 2014.

[11] Australian Renewable Energy Agency, “Technology Readiness Levels for Renewable Energy Sectors,” Commonwealth of Australia, 2014.

[12] P. Graham, J. Hayward, J. Foster and L. Havas, “GenCost 2021-22: Final report,” CSIRO, 2022.

[13] T. Stehly, P. Beiter and P. Duffy, “2019 Cost of Wind Energy Review,” National Renewable Energy Laboratory (NERL), 2020.

[14] J. Hayward, "Wave energy cost projections," Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2021.

[15] G. Smart and M. Noonan, "Tidal Stream and Wave Energy Cost Reduction and Industrial Benefit - Summary Analysis," CATAPULT Offshore Renewable Energy, Glasgow, 2018.

[16] P. Konstantin and M. Konstantin, The Power Supply Industry : Best Practice Manual for Power Generation and Transport, Economics and Trade, Baden-Wurttemberg: Springer, 2018.

[17] A. A. Kebede, T. Kalogiannis, J. Van Mierlo and M. Berecibar, "A comprehensive review of stationary energy storage devices for large scale renewable energy sources grid integration," *Renewable and Sustainable Energy Reviews*, no. 159, 2022.

[18] O. Schmidt, S. Melchior and I. Staffell, "Projecting the Future Levelized Cost of Electricity Storage Technologies," Joule, 2019.

[19] Geoscience Australia, Solar Energy, [Online]. Available: https://www.ga.gov.au/scientific-topics/energy/resources/other-renewable-energy-resources/solar-energy.

[20] Bureau of Meteorology, "Sunshine: Average Daily Sunshine Hours," Bureau of Meteorology.

[21] Geoscience Australia, "Australia's Wind Energy Resources," Geoscience Australia, [Online]. Available: https://www.ga.gov.au/scientific-topics/energy/resources/other-renewable-energy-resources/wind-energy.

[22] N. Nikora, "Wave Energy - Lecture 2, Marine & Wind Energy Course," University of Aberdeen, Aberdeen, 2023.

[23] University of Western Australia, "M4 Metocean Condition Technical Report OGS-M4-2022-001," University of Western Australia, 2022.

[24] P. M. e. al., "Wave energy resource variation off the west coast of Ireland and its impact on realistic wave energy converters' power absorption.," *Applied Energy*, vol. 224, pp. 205-219, 2018.

[25] R. B. e. al., "Quantifying wave power and wave energy converter array production potential," *International Journal of Marine Energy*, vol. 14, pp. 143-160, 2016.

[26] S. D. e. al., "Evaluation of Various Technologies for Wave Energy Conversion in the Portuguese Nearshore,," *Energies*, vol. 6, pp. 1344-1364, 2013.

[27] O. J. e. al., “Variability of wave power production of the M4 machine at two energetic open ocean locations: Off Albany, Western Australia and at EMEC,” *Renewable Energy*, no. 197, pp. 417-431, 2022.

[28] Windy, “Wind Map & Weather,” [Online]. Available: www.windy.com.

[29] D. A. Griffin, M. Herzfeld, M. Hemer and D. Engwirda, “Australian tidal currents – assessment of a barotropic model (COMPAS v1.3.0 rev6631) with an unstructured grid,” *Geoscientific Model Development*, vol. 14, pp. 5561-5582, 2021.

[30] B. R. (Ed.), Handbook of Distributed Generation: Electric Power Technologies, Economics and Environmental Impacts, Cham, Switzerland: Springer, 2017.

[31] K. Mongird, V. Viswanathan, J. Alam, C. Vartanian, V. Sprenkle and R. Baxter, “2020 Grid Energy Storage Technology Cost and Performance Assessment,” U.S. Department of Energy, 2020.

[32] M. Taylor, “Falling Costs Drive Strong Demand for Australia’s Residential Solar PV (Expert Insights),” IRENS, 20 05 2002. [Online]. Available: https://www.irena.org/News/expertinsights/2022/May/Falling-costs-drive-strong-demand-for-Australias-residential-solar-PV. [Accessed 2022].

[33] V. Ramasamy and R. Margolis, “Floating Photovoltaic System Cost Benchmark: Q1 2021 Installations on Artificial Water Bodies,” National Renewable Energy Laboratory (NREL), 2021.

[34] J. Hayward, “Wave energy cost projections: A report for Wave Swell Energy Limited,” Commonwealth Scientific and Industrial Research Organisation (CSIRO), 2021.

[35] M. O'Connor, T. Lewis and G. Dalton, “Operational expenditure costs for wave energy projects and impacts on financial returns,” *Renewable Energy*, no. 50, pp. 1119-1131, 2013.

[36] Australian National Maritime Museum, “Sponsors,” 2022. [Online]. Available: https://www.sea.museum/support/sponsors. [Accessed 17 Jan 2023].

[37] Clean Energy Regulator, “Small-scale systems eligible for certificates,” Government of Australia, 19 Jan 2023. [Online]. Available: https://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Agents-and-installers/Small-scale-systems-eligible-for-certificates. [Accessed 24 Jan 2023].

[38] Clean Energy Regulator, “Large-scale generation certificate general formula,” Government of Australia, 29 Oct 2019. [Online]. Available: https://www.cleanenergyregulator.gov.au/RET/Scheme-participants-and-industry/Power-stations/Large-scale-generation-certificates/Large-scale-generation-certificate-eligibility-formula. [Accessed 23 Jan 2023].

[39] NREL, “Annual Technology Baseline: Commercial Battery Storage,” NREL, 2022. [Online]. Available: https://atb.nrel.gov/electricity/2022/commercial_battery_storage. [Accessed 2023].

[40] Demand Manager, “Certificate Report December 2022,” Demand Manager Pty Ltd, 2022. [Online]. Available: https://www.demandmanager.com.au/certificate-prices/. [Accessed 23 Jan 2023].

[41] Australian Bureau of Statistics, “Regional Population,” 2021. [Online]. Available: https://www.abs.gov.au/statistics/people/population/regional-population/latest-release.

[42] G. Allan, M. Gilmartin, P. McGregor and K. Swales, “Levelised costs of Wave and Tidal energy in the UK: Cost competitiveness and the importance of "banded" Renewables Obligation Certificates,” *Energy Policy*, vol. 39, no. 1, pp. 23-29, 2011.

[43] A. Government, “Regional Strengths and Infrastructure Gaps: Regional Analysis, Western Australia,” Infrastructure Australia, 2022.

Table 1-1. Scenario Phase 2, Option 2b – installed capacity and reliance on back-up supply 8
Table 1-2. Scenario Phase 2 estimated CAPEX and OPEX by installed renewable generation capacity, unadjusted for inflation. 8
Table 6-1. ARENA technology readiness levels [10]. 34
Table 6-2. Technology review - renewable energy generation. 36
Table 6-3. Technology review - energy storage. Sources include Kebede et al paper [17] and the Schmidt et al study from Joule [18]. 37
Table 6-4. Summary of solar irradiance data. 40
Table 6-5. Summary of mean wind speed data. 44
Table 6-6. Summary of two wave measurement campaigns. 45
Table 6-7. Comparison of tidal elevation and major axis velocity amplitudes between regions. 49
Table 6-8. Overview of electricity demand scenarios. 53
Table 6-9. All scenarios - components of electricity demand. 54
Table 6-10. Electricity demand - statement of assumptions. 55
Table 6-11. Scenario 1 - components of electricity demand. 56
Table 6-12. Scenario 2 - components of electricity demand. 57
Table 6-13. Scenario 3 - components of electricity demand. 59
Table 6-14. Scenario 4 - components of electricity demand. 61
Table 6-15. Scenario 5 - components of electricity demand. 63
Table 6-16. Data sources used in renewable resource assessment. 69
Table 6-17. Summary of cost input assumptions and outputs developed and modelled during the study. 71
Table 6-18. Scenario 1 – summary of installed capacity options and their reliance on back-up supply. 82
Table 6-19. Scenario 2 – summary of installed capacity options and their reliance on back-up supply. 85
Table 6-20. Scenario 3 – summary of installed capacity options and their reliance on back-up supply. 88
Table 6-21 Summary of installed capacity options and their reliance on back-up supply. 90
Table 6-22. Scenario 5 – summary of installed capacity options and their reliance on back-up supply. 92

Figure 1-1. South-Western Australian population density, electricity grid access and power generation. 5

Figure 1-2. Seasonal variability of renewable resource at project site. 7
Figure 1-3 Scenario Phase 2 – Hourly electricity demand profile 7
Figure 1-4. Forecasted gross revenue for the marketplace, adjusted for inflation. 9
Figure 2-1: Conceptual Diagram of an Integrated Ocean Energy System (AOEG). 14
Figure 2-2: Further onshore details of a Conceptual Diagram of an Integrated Ocean Energy System (AOEG). 15
Figure 2-3. General project development roadmap. 16
Figure 3-1. Albany's Historic Whaling Station location at Discovery Bay. 18
Figure 3-2. Aerial view of Albany's Historic Whaling Station location. 19
Figure 4-1 Artist's impression of the Conceptual Ocean Energy Marketplace 21
Figure 4-2. Indicative breakdown of various drivers for the Marketplace. 22
Figure 5-1. The future transformation of the SWIS, adapted from Western Power [5]. 24
Figure 5-2. Map of the SWIS and the transmission network zones (nodes). 25
Figure 5-3. Albany Region Electricity Network [modified from Western Power Network Capacity Mapping Tool [6]]. 26
Figure 5-4. Discovery Bay Electricity Network Access [modified from Western Power Network Capacity Mapping Tool [6]]. 27
Figure 5-5. SWIS weekly (top and left) and 12th November 2022 midday (right) electricity generation by energy type [7]. 28
Figure 5-6. Australian population density, electricity grid and power generation. 30
Figure 5-7. South-Western Australian population density, electricity grid and power generation. 31
Figure 5-8. Greater Adelaide population density, electricity grid and power generation. 32
Figure 5-9. Population Growth in Significant Coastal Urban Areas of Australia [41]. 32
Figure 6-1. Annual mean solar irradiance at Discovery Bay, 2001-2020. 38
Figure 6-2. Monthly mean solar irradiance at Discovery Bay, 2001-2020. 39
Figure 6-3. Hourly mean solar irradiance at Discovery Bay, 2001-2020. 40
Figure 6-4. Annual mean wind speeds at Discovery Bay, 2001-2020. 42
Figure 6-5. Monthly mean wind speeds at Discovery Bay, 2001-2020. 42
Figure 6-6. Hourly mean wind speeds at Discovery Bay, 2001-2020. 43
Figure 6-7. Monthly mean significant wave height. 46
Figure 6-8. Monthly mean peak period. 46
Figure 6-9. Monthly mean wave power level. 47
Figure 6-10. Percentage of occurrence of significant wave height and mean period. Measurements obtained using the Spotter [23]. 47
Figure 6-11. Current tidal speeds within King George Sound, from the Windy app. 48
Figure 6-12. Seasonal variability of renewable resource at project site. 50
Figure 6-13. Monthly variability in renewable resource at project site. 51
Figure 6-14. Hourly variability in renewable resource at project site, January. 51
Figure 6-15. Hourly variability in renewable resource at project site, July. 52
Figure 6-16. Scenario 1 - share of annual electricity demand by component (in MWh). 56
Figure 6-17. Scenario 1 - hourly electricity demand profile. 57
Figure 6-18. Scenario 2 - share of annual electricity demand by component (in MWh). 58
Figure 6-19. Scenario 2 - hourly electricity demand profile. 59
Figure 6-20. Scenario 3 - share of annual electricity demand by component (in MWh). 60
Figure 6-21. Scenario 3 – large-scale desalination hourly electricity demand profile. 60
Figure 6-22. Scenario 3 - hourly electricity demand profile (excluding large-scale desalination). 61

Figure 6-23. Scenario 4 - share of annual electricity demand by component (in MWh). 62
Figure 6-24. Scenario 4 – large-scale desalination hourly electricity demand profile. 62
Figure 6-25. Scenario 4 - hourly electricity demand profile (excluding large-scale desalination). 63
Figure 6-26. Scenario 5 - share of annual electricity demand by component (in MWh). 64
Figure 6-27. Scenario 5 - hourly electricity demand profile. 64
Figure 6-28. All scenarios – annual electricity demand with significant components highlighted. 65
Figure 6-29. All scenarios – hourly electricity demand profile. 66
Figure 6-30. Energy system model schematic. 67
Figure 6-31. Energy system operating modes. 68
Figure 6-32. Current and projected generation technology capital costs under the Global NZE post scenario. 70
Figure 6-33. Capital costs for onshore solar PV excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity [12, 32]. 72
Figure 6-34. Capital costs for FPV excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [12, 32]). 73
Figure 6-35. Capital costs for onshore wind implementation excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [13]). 73
Figure 6-36. Capital costs for offshore wind – fixed bottom excluding insurance and contingency (in real terms 2022) for the various levels of installed capacity (adjusted from [13]). 74
Figure 6-37. Onshore solar PV LCOEs calculated for the various scenarios for energy supply in Albany. 75
Figure 6-38. Floating solar PV LCOEs calculated for the various scenarios for energy supply in Albany. 75
Figure 6-39. Onshore wind LCOEs calculated for the various scenarios for energy supply in Albany. 76
Figure 6-40. Offshore wind fixed bottom LCOEs calculated for the various scenarios for energy supply in Albany. 76
Figure 6-41. Wave energy LCOEs calculated for the various scenarios for energy supply in Albany. 77
Figure 6-42. Renewable power generation example. 78
Figure 6-43. Electricity demand example. 78
Figure 6-44. Renewable power to demand example. 78
Figure 6-45. Renewable power to battery example. 79
Figure 6-46. Curtailed renewable power example. 79
Figure 6-47. Reserve power to demand example. 79
Figure 6-48. System LCOE of the high, intermediate and low cost/reliance Scenario 1 options, with and without renewable generation oversizing, and a range of energy storage capability. 83
Figure 6-49. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance scenario 1 options, with and without renewable generation oversizing. 84
Figure 6-50. System LCOE of the high, intermediate and low cost/reliance Scenario 2 options, with and without renewable generation oversizing, and a range of energy storage capability. 86
Figure 6-51. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 1, with and without renewable generation oversizing. 87
Figure 6-52. System LCOE of the high, intermediate and low cost/reliance scenario 3 options, with and without renewable generation oversizing, and a range of energy storage capability. 88
Figure 6-53. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance Options for Scenario 1, with and without renewable generation oversizing. 89
Figure 6-54. System LCOE of the high, intermediate and low cost/reliance options for Scenario 4, with and without renewable generation oversizing, and a range of energy storage capability. 91
Figure 6-55. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 4, with and without renewable generation oversizing. 91

Figure 6-56. System LCOE of the high, intermediate and low cost/reliance options for Scenario 5, with and without renewable generation oversizing, and a range of energy storage capability. 93
Figure 6-57. Annual reserve energy needed to balance supply and demand for the high, intermediate and low cost/reliance options for Scenario 5, with and without renewable generation oversizing. 94
Figure 7-1 General Project Development Roadmap 96