Master of Science - Thesis Research

An analysis of the market potential for ocean renewable energy in industrial maritime sectors of Australia's Blue Economy

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In partnership with the
Australian Ocean Energy Group (AOEG)
&
Commonwealth Scientific Industrial Research Organisation (CSIRO)
&
Climate KIC Australia

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Abstract

The energy system in Australia is dominated by fossil fuels and is slowly adopting renewable energy sources for power generation. As the national economy relies in large part on coal and natural gas export earnings, Australia is lagging behind more climate-conscious countries in the implementation of policies to promote energy efficiency and emissions reductions.

Global and internal pressures are challenging the future of Australia's energy system and throwing into question the bases for the country's economic wellbeing. Yet, Australia is one of the largest offshore coastal territories, classified as the Blue Economy, where its infinite marine resource area offers a sizeable opportunity for adopting ocean renewable energy (ORE) as an alternative low carbon source input for large scale industrial sectors.

The scope of the research follows a mixed-methods approach to identify the market potential for tidal and wave technology in three marine sectors. The thesis carries out a technical and economic potential analysis for ORE power capacity in marine sectors and subsequent emission abatement. Additionally, a review of the current legislative framework is made with direct opinions from interviews in order to propose ways to overcome policy and financial barriers.

Preliminary results show that there is high market opportunity to integrate ocean energy for Aquaculture and Ports activities, and a low market potential for Oil & Gas industries. The increasing contribution of innovation and scientific research from interdisciplinary actors and organisations, presents a case for integrating tidal turbines and wave energy converters in marine sectors with economic importance in an international and significant way that can contribute to the sustainable energy transition in Australia.

Contents

Abbreviations

ABN: Australian Business Number
ACT: Australian Capital Territory (Australian State)
AFMA: Australian Fisheries Management Authority
AHT: Anchor Handling Tug
AIMS: Australian Institute of Marine Science
AMC: Australian Maritime College
AOEG: Australian Ocean Energy Group
AU: Australia
AU$: Australian Dollar
AWEP: Albany Wave Energy Project
BAU: Business as usual
BE-CRC: Blue Economy Cooperative Research Center
BTU: British Thermal Units
CFA: Commonwealth Fisheries Association
CH_4: Methane
CO_{2-e}: Carbon dioxide (equivalent)
CSG: Coal Seam Gas
CSIRO: Commonwealth Scientific and Industrial Research Organization
CSR: Corporate Social Responsibility
EE(I): Energy Efficiency (Improvement)
EMEC: European Marine Energy Centre
EMF: Environmental Management Framework
Envr.: Environmental
EWEC: European Wave and Tidal Energy Conference
FPSO: Floating Production Storage and Offloading (system facility)
FRDC: Fisheries Research and Development Corporation
FTE: Full time equivalent
FY: Financial Year
GHG: Greenhouse gas emissions
GJ: Gigajoules
GOC: Government owned corporation
GPC(L): Gladstone Ports Corporation (Limited)
GVA: Gross Value Added
GVP: Gross Value of Production
HOG: Head on Gutted
HSE: Health, Safety and Environment
ICE: Intelligent Community Energy (project)
ICOE: International Conference on Ocean Energy
ICTWP: International Conference on Tidal and Wave Power
IEA: International Energy Agency
J: Joules
Kg: Kilogram
Kg/BOE: Kilogram per barrel of oil equivalent
kJ/m^3: Kilojoules per meter cubed
Km: Kilometer
Kn: Knotts
KPA: Kimberley Pots Authority
Kt: Kilotonnes
kW: Kilowatts

LCOE: Levelised Costs of Electricity
LNG: Liquefied Natural Gas
LPG: Liquefied Petroleum Gas
m/s: Meters per second
MMBOE: Millions of barrels of oil equivalent
MMSCF/d: Million standard cubic feet per day of gas
MMSTB: Million stock barrels
Mng: Management
Mt: Million tonnes
MTPA: Million tonnes per annum
MW(h): Megawatt (hour)
NEM: National Electricity Market
NERA: National Energy Resources Australia
NGER: National Greenhouse and Energy Reporting
NT: Northern Territory (Australian State)
NW: North West
NZ: New Zealand
O&G: Oil & Gas
ORE: Ocean Renewable Energy
OWC: Oscillating Water Column
PB: Port of Broome
PBP: payback period
PE: Port of Esperance
PI: Port of Brisbane
PoG: Port of Gladstone
PPAs: Power Purchase Agreements
PT: Port of Townsville
Q&A: Questions and Answers
QL: Queensland (Australian State)
R&D: Research and Development
RE: Renewable Energy(ies)
ROI: Return on Investment
ROPE: Remote Ocean Power Enabler (project)
ROVs: Remotely Operated Vehicle
SA: South Australia (Australian State)
SDGs: Sustainable Development Goals
Sust.: Sustainability
SWOT: Strength, Weaknesses, Opportunities, Threats
TAS: Tasmania (Australian State)
TEU: Twenty-foot equivalent unit
TJ: Terrajoules
UN SDGs: United Nation Sustainable Development Goals
UQ: University of Queensland
VIC: Victoria (Australian Sate)
WA: Western Australia (Australian State)
WSE: Wave Swell Energy

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1. Introduction

The global energy and power system continues to be led by fossil fuels with increase introduction of renewable technologies (Thompson, 2020). Human activity is dependent on energy and the overall demand is increasing, but the supply of primary conventional resources for electricity generation is dwindling. Industrial sector activity is growing larger to meet the incessant human activity. The required energy demand that follows is creating an imbalance in the planet's climate system resulting in extreme weather events, resource depletion, and pollution. As a result, the development and use of renewable energy has experienced expansion and discussion in the last decade. In the present crisis of climate change some countries are more advanced in integrating lower carbon alternatives into the energy mix, while others, such as Australia are lagging behind. This research posits that there is an urgency for a faster transition to clean energy in Australia, for which ocean renewable energy (ORE) can serve as an alternative source within marine industrial activities (Kenyon 2019).

1.1 Energy in Australia

Australia is a central figure in energy supply, exporting over 75% of its energy output to world markets with 20% of total export for industries (Geoscience Australia, 2019). Australia has a structural economic dependency on fossil fuels with large fossil fuel industries playing an important role and influence on the climate policy (Warren, Christoff, & Green, 2016).

Australia is predominantly dominated by fossil fuels due to the low-cost and abundant coal (Table 2). Energy consumption in 2017-18 was dominated by oil (39%), coal (30%) and natural gas (25%) (Dept. Envr. & Energy, 2019, p.9). While Australia is responsible for approximately 1.3% of global emissions, fossil fuels make up 94% of Australia's primary energy mix. Coal continues to lead the Australian energy production mix with 66.5% share among all fuels (Table 2). The International Energy Agency reports the key energy statistics for Australia in 2018 (Table 1) and mentions that the power system is experiencing a move toward the adoption of renewable energy (RE), discussed further in this report (IEA, 2018). At the end of 2019, Australia was one of the world's top exporter of Liquefied Natural Gas (LNG), with exports expected to reach AU$299 billion in 2019-2020 compared with a total Gross Domestic Product (GDP) of AU$1,930.4 billion (Dept. Indus., 2020, p.4). LNG exports are expected to reach 81 million tonnes (mt) over the next year, 2020-2021 and 79 mt by 2022-2023, with earnings expected to range between $44-$47 billion in the time five-year time period, 2020-2025 (Dept. Indus., 2020, p.61).

Table 1: Energy statistics in Australia for the year 2018 (IEA, 2018).

Energy source type	Value
Energy Production	412 Million tons oil equivalent (Mtoe)
Primary Energy Supply	128 Mtoe
Electricity Final Consumption	248 Terrawatt hours (TWh)[1]
Carbon Dioxide (CO_2) Emissions	383 Million tons (Mt) CO_2

Table 2: Description of fossil fuel activity in Australia for the year 2019 recorded as of March 2020 (Dept. Indus, 2020).

Energy source	Description
Steel (p.26)	5.3 million tons output per year 100,000 employed Export markets (china, Japan, Singapore, U.S.)
Thermal Coal (p.47)	2nd largest global exporter; 75%-80% coal exported
Gas (p.60)	77 million tonnes exported AU$49 billion export earnings
Oil (p.71)	AU$10 billion export worth (3% of oil production)

Electricity

Australia is one of the highest per capita emitter of CO_2, with 86% of electricity sources being from fossil fuels (Warren et al., 2016). While there is a heavy reliance on finite sources in the Australian energy system, there is a growth of renewable energy sources as inputs for electricity conversion since 2016 (Table 3).

Table 3: Australian primary energy sources for electricity generation in 2018 and 2019.

Electricity primary energy sources			
Year	**Fossil fuels**	**Renewables**	**Reference**
2018	81.00%	<20%	Dept. Envr, 2019, p.29
2018	79%	21%	CEC, 2020
2019	76%	24%	CEC, 2020

Renewable Energy

In 2019, Australia's RE capacity grew by 2253 Megawatts (MW)[2] with large scale photovoltaic (PV) solar energy constituting approximately two thirds of capacity and contributing 24% of added capacity to total electricity generation (CEC, 2020). At the end of the same year, there was

[1] * 1 TWh = 10^{15} Watt-hours; 1 Watt-hour = 3600 Joules (J)

[2] 1 Megawatt = 10^6 Watts

11.9 Gigawatt (GW)[3] new generation renewable technology under construction worth AU$20.4 billion and creating over 14,500 jobs (CEC, 2020). The RE generation amounted to 55,093 GWh in 2019. Wind energy accounts for 35.4% of RE generation, taking the lead over hydro (25.7%) (Figure 1). Renewable energy development is more efficient in primary energy-to-power conversion and lower emitting when compared to conventional fossil fuels. There is a subsidy scheme for solar systems and since solar has experience in deployments, it has become mature source of RE (Neoen, 2020).

Figure 1: Percentage distribution of renewable energy in Australia at the end of 2019 (CEC, 2020).

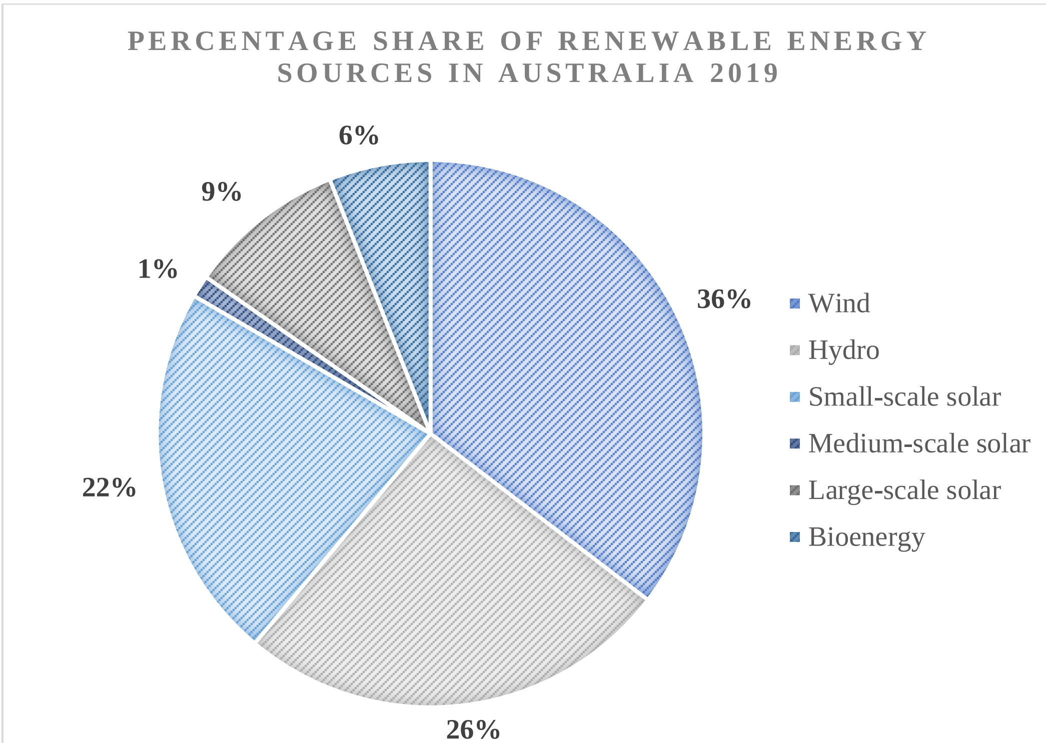


Figure 1 shows that ocean renewable energy is minimal in Australia and does not yet account for primary energy source in power conversion. Medium-scale and small-scale solar make up over 50% of the renewable energy share. Hydro accounts for at least a quarter of total primary energy sources in 2019, which can further stimulate a move toward adopting ocean sources for power generation over the next decade in Australia. The urgency to implement ORE is further highlighted by the International Energy Agency (IEA) tracking power progress report (2020), where data shows that marine technologies need a rapid deployment through 2030 to match the sustainable development scenario (SDS) of ocean power (i.e. 4 TWh by 2020 and 15 TWh by 2030).

[3] 1 Gigawatt = 10^3 MW

Policies

The current energy regimes are unsustainable if measures are guided to keep global warming below 2°C under the Paris Agreement, UNFCCC target (Warren, et al., 2016). Australia has pledged – under the Paris Agreement – to 5% emission reduction below 2000 levels by 2020, and a minimum of 26%-28% by 2030 from 2005 baseline levels (Hemer et al., 2017). The country is working towards climate change energy targets established in early 2000's (Australian Government, 2015). Warren et al., (2016) describe the policy approaches and evolution of the government discourse to help the country move away from carbon, energy intensive activity (Table 4).

Table 4: History of government bodies, committees and activities in Australia relating to climate change and energy policies (adapted from Warren et al., 2016).

Date	Description
2004	Emissions Trading Taskforce established to introduce a national market-based carbon pricing mechanism.
2007	New department of climate change and energy efficiency is established.
2008	Rudd Labor government elected and proposes Carbon Pollution Reduction Scheme (CPRS) – a cap and trade system for Australian businesses.
2009	CPRS legislation was voted down by the elected political system (Climate Alliance, 2016).
2011	MultiParty Climate Change Committee – carbon pricing mechanism considered and developing Clean Energy Agreement. Establish ambitious 2050 target for emissions reductions of 80% below 2000 levels (MPCCC, 2011)
2012	Carbon price meant to start with fix price period at $23 per tonne CO_{2-e}
2013	Election of Liberal Party (center right politics) of Australia after Labor Party (center left politics) prime minister served from 2007-2013.
2018	Prime Minister Scott Morrison – corporate advisers have background in fossil fuel industry and are pushing for gas-led recovery for Australia's low-emissions future (Murphy, 2020).

The above table shows there is limited climate policy that exists or that is evolving in Australia, and the current government is not helping to improve performance with legislative actions. Australia faces climate risks considering it received the lowest rating with a score of 0.0 out of 100.00 in this year's 2020 Climate Policy Rating published by the Climate Change Performance Index (CCPI), and ranks as the 6th worst-performing country (out of 57 countries) (Martin, 2019).

In 2017, the federal government introduced the National Energy Guarantee to regulate emission reduction and help provide a reliable electricity retail market (REN21, 2018). Australia has introduced management schemes to help balance integrated variable RE systems.

There is a written national climate change adaptation strategy with the following mitigation actions:

To enhance energy efficiency
To increase uptake of RE
To improve industrial processes, (e.g. maintenance, operation of production systems)
(Dept. of Agri, 2015).

The research plan abovementioned is a function of the National Climate Change Adaptation Research Facility (NCCARF), established in 2008 by the Australian Government, with the mission to inform decision-makers and build the capacity to manage the risks of climate change impacts (n.d.); However, the lack of guidance and detail makes the strategy weak. There is the Climate Change Authority (CCA), established under the Act 2011, which provides analysis into climate change issues and advice relating to the Carbon Credits Initiative and National Greenhouse Emission Reporting (NGER) Act of 2007 (2019). There is also the Clean Energy Regulator (CER) that administers schemes led by the Australian government to manage and offset the country's carbon emissions (2018). The CER is responsible for collecting and publishing data, work with regulatory bodies, provide education and information, and accredit auditors for the administered schemes.

The CER acts as an economic regulator with overview on the following schemes:

1. NGER system
2. Emissions Reduction Fund
3. RET – Act 2000

The NGER is an emission and energy reporting system for all reporting under the Act 2007 administered by Industry, Science, Energy and Resources (CER, 2020a).

The Emissions Reduction Fund (ERF) is enacted though the Carbon Credit Act 2011; a voluntary scheme that incentivizes organisations and individuals to partake in new practices and technologies that can reduce emissions (CER, 2016). The government invested AU$300 million, AU$500 million and AU$750 million over a period of three years for the ERF (NIEIR, n.d.). Participants can earn Australian Carbon Credit Units (ACCUs) for emissions reductions through a variety of activities. Specifically, one ACCU is earned per tonne of carbon dioxide equivalent ($tCO_{2\text{-}e}$) stored or mitigated by a project (CER, 2016). A safeguard mechanism is built under the fund where business activities are to keep emissions within a certain range.

The Renewable Energy Target (RET) scheme encourages investment in renewable power stations (i.e. wind, solar farms, hydro-electric power stations) to achieve the large-scale RET of an additional 33,000 GWh renewable electricity generation by 2020 (CER, 2018). There is also a small scale RET that supports installations on smaller scale (e.g. rooftop solar for households).

The aforementioned comment ties to the fact that climate change targets set beyond 2030 were not identified in the literature. In Australia, there is a strong link between the energy system and the health of the economy, thus sufficient access to energy is important for economic development and human wellbeing (PWC, 2019). Li, Chalvatzis & Papps (2017) suggest that to maintain the 2°C climate change objective, it is necessary to first set a carbon intensity target for electricity generation (Martek et al., 2019, p. 282). Another strategy is to source power production from low carbon technologies or from renewables. A major issue is that the federal government is still pushing for coal to secure energy production, which will likely grow emissions by 2030 rather than reducing emissions in accordance to the nation's 2030 commitment (Nicholson, 2019). Reducing carbon intensity is urgent considering that electricity generation in Australia is the largest emitting industry representing 35% of total emissions and electricity inputs come from over 50% of fossil fuel sources (Wolfram, Wiedmann, & Disendorf, 2016). On a positive note, the Australian government published that energy intensity decreased (-1.9%) and energy productivity increased (2.0%) reaching 245AU$m/PJ in 2017-18. The energy intensity in Australia amounted to 3,4901.3 GJ/AU$m (Dept. Envr., 2019, p.15).

A key method for Australia's Sustainable Energy Transition (SET) is to pursue an integrated approach for the design and implementation of climate and energy policies. Jarvinen (2019) confirms that a true transformation can be made possible through collaboration and compiling of knowledge across sectors (e.g. renewable energy, offshore industries, coastal market activities). Actually, Australia is implicated in the matter with the newly launched Blue Economy Cooperative Research Center (BE CRC) initiative.

1.2 Blue Economy

Australia's marine industries make up a significant component of the national economy with the latest statistics showing that marine industries account for 4.8% of GDP and provide over 40,000 new employments (Moltmann, 2017). Table 5 illustrates the economic importance of the marine sector recorded in the Index of Marine Industry Report records (AIMS, 2018).

Table 5: Description of the economic contribution of Australia's marine industrial sectors recorded in 2015-16 (AIMS, 2018, p.7). *All values are in Australian Dollar.*

Value	Description
$68.1 billion	Total measurable output (income) attributable to marine environment (see Table 6 for sub-sector detail)
$39.8 billion	Direct contribution, value added
$31.6 billion	Indirect contribution, value added in other industries
$71.4 billion (4.3 % GDP)	Total contribution in value added, percentage of national gross domestic product
393, 000 FTE workers	Total employment Full Time Equivalent (FTE)
197,000 (50.1%) FTE workers	Directly employed by the maritime industry

The value added from each specific marine industry to the overall Australia's economy is in the folds of billions of dollars (Table 6); this economic significance motivates the choice to select the marine sector for the potential to redirect investments toward renewable energy, especially ocean sources.

Table 6: Contribution of marine-related activities per sub sector in 2015-2016 (AIMS, 2018, p.12). *All economic values are in Australian dollar.*

Value	Description
$1,307 million	Marine-based aquaculture
$16,546 million	Natural Gas
$4,968 million	Oil production
$1,278 million	Oil exploration
$547 million	LPG: Liquefied Petroleum Gas
$719 million	Marinas and boating infrastructure

The Blue Economy (BE) emerged as a concept in response to the 2012 United Nations Conference on Sustainable Development and a focus on oceans as key driver for environmental protection (Voyer, Quirk, McIlgorm, Azmi, Kaye & McArthur, 2017). Voyer et al., (2017) identify four streams for oceans of which two are related to the scope of this research: i) oceans as good business and ii) oceans as a driver of innovation, with objectives to i) push for multi-national growth of knowledge from academia, industry and government as well as to ii) advance technological research and investment for strategies in emerging industries. The aforementioned concepts are important to bring forward ocean-based development and governance in industries within the BE, and are used as thematic oversight for the research.

In 2015, the National Marine Science Plan 2015-2025 was launched to provide scientific recommendations to help overcome energy security, climate change and maritime sovereignty challenges to generate wealth and wellbeing for future generations (NMSC, 2020). The Ocean Policy Science Advisory Group estimates that Australia's oceans may contribute up to AU$100 billion to the economy by 2025 (AIMS, 2018, p. 9). In 2019, the BE CRC was established with the mission to address the lack of knowledge on ways to operate effectively in offshore environments (OES, 2020). The government has allocated over AU$70 million for more than 10 years into the BE CRC to support five main research programs (Hon Karen, 2020; Table 7). The BE CRC assembles over 40 participants with diverse expertise and sectors in order to develop the sustainable production of food and energy in Australia (2019). The cooperative mingles knowledge in marine renewable energy, offshore engineering and commercial enterprises with the aim to change energy output and seafood production.

Table 7: Description of the five research programs led by the BE CRC (2019a).

Research Program Title	Description/objective
Offshore Engineering & Technology (OET)	Obtain commercialised designs for high-energy offshore aquaculture pens. Create first multi-use platform for commercialisation and quantification of synergistic benefits of operation. (BE CRC, 2019b)
Seafood & Marine	Advance understanding of and improve fish performance in offshore environments. Integrate production and engineering technologies. (BE CRC, 2019c)
Offshore Renewable Energy (ORE) Systems	Advance management strategies for commercial readiness of emerging ORE technologies to help decrease environmental impact, capital, and operating costs. Develop an energy demand and optimisation model for offshore industry operations. (BE CRC, 2019d)
Environment & Ecosystems	Develop multi-criteria tool for the identification of sites that would support technical and economically feasible locations for integrated multi-use platforms. Smart monitoring and information guidelines relating to (dis)advantages and trade-offs with co-location of operations on multi-use platforms. (BE CRC, 2019e)
Sustainable Offshore Developments	Advocate for the regulatory frameworks that will help in confident investment for offshore development. Establish cost effective assessments, planned approach to manage supply chains and make recommendations for improvement in blue economy activities. (BE CRC, 2019f)

From the table above, the thesis focuses principally on the research program #3, highlighted in grey, which is led by Dr. Hemer, the collaborative entity in this research. Aspects of the other research programs, such as OET and sustainable offshore development inevitably play a role in the overall analysis and discussion pertaining to the research questions.

The Australian Institute of Marine Science (AIMS) considers 14 sub-sectors within the marine industry, which can be further grouped into five main categories (Table 8). The percentage economic contribution of each sub-sector is shown in Figure 2. The Forum for Operational Oceanography (2017) writes that in the last decade, the BE has grown by over 50% with energy resources industries (i.e. LPG, LNG, and petroleum) contributing significantly to economic activity.

Table 8: Marine Industry sub-sector classification (AIMS, 2018, p.12).

Marine Industry sub-sector group	Individual sub-sectors
Fishing and Aquaculture	Recreational and commercial fishing; marine-based aquaculture
O&G exploration and extraction	Natural gas; oil production and exploration; LPG
Building, maintenance and infrastructure	Shipbuilding and repair; marine equipment retailing; boatbuilding; marinas and boating infrastructure
Marine Tourism	Domestic and international consumption of tourism goods and services
Water Transport	Transport of passenger and freight

Figure 2: Economic contribution of marine industries in 2015-2016 per sub-sector category (adapted from AIMS, 2018, p. 12) (Author's own).

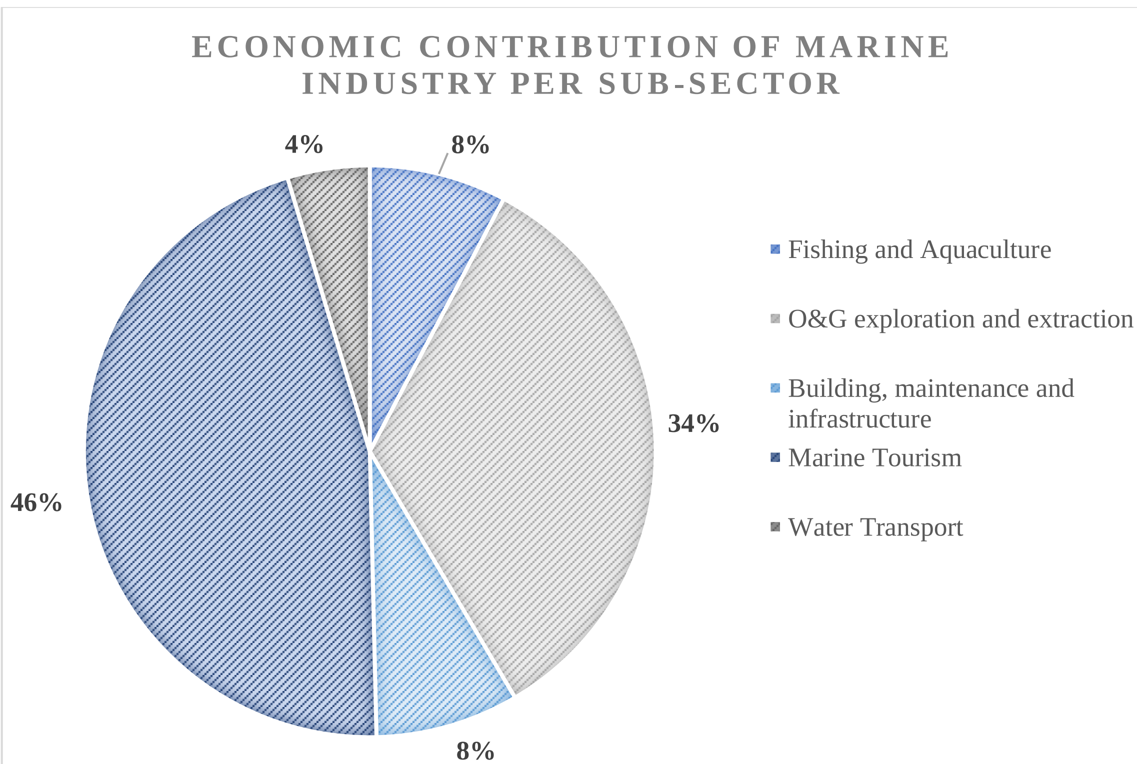


Figure 2 suggests that the two largest sectors contributing to Australia's national economy, with most recent data available for the years 2015-2016, are marine tourism (AU$ 30,873 million) followed by O&G related activities (AU$22,792 million). Fishing & Aquaculture and shipbuilding maintenance and infrastructure contribute a similar value AU$5,246 million and AU$5,474 million, respectively. It is important to note that some economic data is unavailable for several activities so the total output is not an exact estimate.

The renewable energy sector is growing exponentially with an increasing demand for low carbon primary source to produce energy (BE CRC, 2019). Teske (2018) writes that it is necessary for all sectors to focus on energy efficiency and supply from a wide range of lower carbon emitting technologies and build an integrative portfolio of renewable energy sources. Changing the fuel mix by sourcing electricity generation from renewables does not mean it will compromise the security of supply nor the economic development for the country (PWC, 2019; Li et al, 2017). Declining costs of renewable technologies are becoming competitive with fossil fuel sources (Mordor Intelligence, 2020). Upcoming alternative non-fossil fuels include ocean resources which are a type of offshore energy that can provide available and accessible forms of electricity.

1.2 Ocean Renewable Energy (ORE)

The country's geographical and physical landscape offers a rich availability and capacity for renewable resource exploitation as well as international and national market expansion for the distribution of cleaner energy. Australia is one of the largest ocean and natural resource territory that requires attention to ensure its socio-economic viability and environmental integrity (Gunn, 2014). The island is the third largest Exclusive Economic Zone (EEZ), where 80% of the area is classified as offshore (OECD, 2003; BE CRC, 2019g). The EEZ is a sea area for which a coastal state holds sovereign rights to explore and use its natural marine resources across a range of marine activities (IUCN, 2020).

The growing scientific research and published articles indicate that there are promising opportunities for ocean resources, which includes three types of energies: wave, tidal and non-tidal ocean flow (Behrens, et al., 2012). Young (2015) writes that there is a vast possibility to exploit ocean energy at a meaningful commercial scale whereby OREs could advance the current small share, (0.01%) of renewable electricity generation, to contribute significantly to the global energy mix by 2030. In Australia, there has been increased recognition and attention to diversify sources of energy in the mix and encourage sector coupling (Salgado, 2019). "The ocean is a vastly untapped resource for energy production considering that it probably stores enough energy in the form of heat, currents, waves and tides to meet worldwide demand for power many times over" (Pelc and Fujita, 2002, p. 471). Ocean sources have the potential to contribute significantly to Australia's future low carbon energy mix. As an offshore energy, wave and tidal resources pose less impact on land use and land cover change (Hemer et al., 2018). OREs have a higher energy capacity predictability and less output variability than wind and solar (Hemer et al., 2018). "The estimated total tidal energy potential in Australia [stands at] 300 GW" where a 1 MW tidal turbine could provide electricity for 600-1200 households (AMC, 2017a). Wind and solar energy hold the highest economic potential and thus dominate the pathways on the supply side; however, the insufficient secured capacity, that is the (in)consistency in available energy input and predictability limits the dispatchable output power (Teske, 2018). Tidal and wave technology produce energy at different times than solar and wind, so can serve as complimentary electricity sources that also help balance the grid's supply and demand (OES, 2020).

Tidal energy is captured through the conversion of the rise and fall of ocean tides and currents that are caused by the natural gravitational pull of the moon and the Earth (EIA, 2019). Generators and turbines are the most commonly used technology to convert tidal energy into electricity (National geographic, 2019). There are two main types of turbines that exist for tidal energy conversion to electricity, vertical and horizontal axis, depending on the axis of rotation with the ground (NOOA, 2020). Tidal power is most developed technology with la Rance, France dam being renown for a significant supply of energy (i.e. 500 GWh/year) (Boyé, 2012).

Wave energy captures energy generated from the movement of waves which causes a change in water volume and consequently, air pressure. Wave energy devices can be located offshore or nearshore and can be mounted (seabed) or floating (buoy). The three main types are the point absorber, OWC and attenuator (EPRI, 2007). The point absorber retrieves energy from all directions and relies on pressure differences. The Oscillating Water Column (OWC) is a partially submerged chamber with air trapped above a column of water that (de)compresses air from the movement of waves entering and exiting the chamber. The attenuator is a long, floating structure placed parallel to the waves, with multiple sections that move in way that can pressurize air to turn turbine or generator. In the end, "Wave power devices are characterized by the method used to capture the energy of the waves" (Boyé, 2012, p.15)

There are on land and offshore installations to capture energy from renewables, for which research and technology development range from early stages to full capacity installations. The BE CRC initiated an Offshore Renewable Energy Systems program for Tasmania to promote "the production of low cost, reliable and clean energy through offshore wind, wave, tidal and emission free hydrogen solutions" (Hon Karen, 2019). In 2012, the Commonwealth Scientific and Industrial Research Organization (CSIRO) Wealth from Oceans Flagship conducted a study, "to assess the potential of ORE in Australia and to identify Research and development gaps and opportunities" (Behrens et al, p.13). Work is progressing on strategies to integrate infrastructure and shared services between seafood production enterprises, renewable energy sectors, and engineering offshore. The current focus is to develop offshore renewable energy amongst high energy-use industrial sectors in order to meet greenhouse gas (GHG) emission reduction goals as well as to enhance energy and food security (Blue Economy, 2019). While there are a number of barriers listed in the literature, solutions exist for ORE uptake, particularly in Australia (Table 9).

Table 9: Barriers and solutions to ORE deployment and commercialization (adapted from OEE, 2020) (Author's Own).

Barriers	Solution
Technical - Power grid access, connection and capacity.	Liberalise power market for integration of ORE, Increase the number of testing facilities, infrastructure and deployment site to reach economics of scale.
Regulatory: limited legislation & support policies.	Standardize permitting and simplify licensing procedures.
Financial: Current high costs of technology.	R&D investment and revenue schemes (e.g. feed-in tariffs, renewable energy certificates) to de-risk devices.
Environmental: potential impacts on marine life, fishing, navigation.	Carry out robust research and environment impact assessments in a variety of contexts and locations.

The challenges presented in Table 9 surrounding ORE deployment can be resolved with international collaboration and involvement of multiple stakeholders. Janssen and Simon (2020) suggest that with meaningful public intervention, tidal and wave technologies can move along the cost curve and reach scaling advantages with larger production. It is important for risks to be properly managed for ORE technology to become commercially viable over the next few years, 2020-2025. Factors (e.g. technical, economic, political) for commercial success of ORE are discussed in the results section.

Ocean energy in Europe

Ocean energy plays an important strategic role in the BE CRC because the offshore industry may serve as a unique power system market opportunity. Europe is a leader in ocean energy development and the strategic pathway can serve as an example for Australia, discussed further in the report. Europe has the long-term goal (2050) to decarbonize the whole economy by 80%-95% (OEE, 2020); in the shorter term, the parliament and member state governments have set a target of 32% renewable energy in the energy mix by 2030. In the last 10 years, Ocean Energy Europe (OEE) has spent over €1 billion in Research and Development (R&D) investment given the estimated global market worth of €53 billion annually in 2050 (OES, 2020). The new industry visions 100 GW of ORE along with 400,000 jobs by 2050. In Europe, tidal energy capacity is leading and wave has been emerging since 2010 (Table 10) (Collombet, 2020).

Table 10: Capacity added and cumulative tidal and wave energy installation in the year 2019 in Europe and globally (Collombet, 2020).

Deployment	Tidal Stream [MW]	Wave Energy [MW]
Capacity added	1.52	0.6
Cumulative installation in Europe since 2010	27.7	11.8
Installation capacity outside Europe (global)	1.8	1.2
Total energy installed ocean energy market	512.5	240
Theoretical potential	1,200 (TWh)	29,500 (TWh)

Table 10 indicates the lead of tidal stream technology with wave energy is emerging both in Europe and across the globe. Several international and Australian companies have pursued entrepreneurial strategies that use renewable ocean energy for electricity supply to be connected to the grid (Behrens et al., 2012). Numerous companies are improving their technology past the prototype stage and closely approaching the commercial development phase. Developments of ocean energy are growing rapidly, where in 2020 there has already been twice the total cumulative capacity added, in one year (Janssen and Simon, 2020).

Australia makes up 31% of total installed wave power capacity globally. Comparing to offshore wind and solar sources, ORE capacity has lower developed capacity since it is an emerging renewable. The strength of ORE lies in its ability to overcome the intermittency of solar and wind as it has a resource availability ranking from 85% and reaching up to 95% (Seanergy, 2016).

Tidal technology has progressed more rapidly than wave energy because there is a convergence of design for tidal turbines. Furthermore, tidal has undergone sustained full-scale testing in operational conditions and reached MW capacity (SI Ocean, 2014). Wave devices still need to undergo large-scale pilot and array demonstration projects to come closer to commercial stage.

1.4 Problem Description

Australia is among the world's 25 wealthiest, developed countries, but remains dependent on fossil fuels for energy (Silver, 2019). Economic imperatives and political pressures that are prioritized over environmental and social agendas, hinders the country from effectively carrying out sustainable energy strategies (Barber & Israel, 2016). Kenyon (2019) writes that the country faces challenges for future energy security and needs to ensure the interdisciplinary role of industry, government and citizens for effective adaptation strategies. The earnings in Australia are dependent on fossil fuels, particularly LNG production, so with the current progress toward net-zero and climate neutrality targets, Australia's economy could be negatively impacted. On a political front, Warren et al. (2016) write that current climate and energy policies are insufficient despite the urgency to move toward low-carbon energy systems to avoid dangerous impacts a dependency on fossil fuels.

Evidence and information are lacking on the risks and opportunities of tidal and wave technology in Australia. Quantitative data is missing to represent the energy demand and electricity consumption of industries within the BE system.

The extreme physical environment for ORE installation and deployment poses challenges to commercial success, and creates financial as well as technological barriers. Limited financial resources in industry are due to the perception of high risk and upfront costs that investors are reluctant to take on or see as potentially profitable. Technical barriers regard grid connection issues and scalability (Young, 2015). Economic barriers include market competition from solar and wind renewable energy suppliers and elevated infrastructure costs.

1.4.1 Knowledge gap

There exists a gap of knowledge on the resource, technical, economic and market potential of tidal and wave energy as an alternative low-carbon source for offshore marine industries in Australia. There is limited information on the carbon emissions associated with industrial sectors within the BE and potential for carbon abatement by adopting ORE technology,

Some of the main concerns include:

1. **Technology readiness level** in Australia (i.e. reliability, power capacity, design, infrastructure)
2. **Commercial preparedness of technology** in Australia (i.e. demonstration projects, test validation)
3. **Costs of technology** and financial support schemes (i.e., operations & maintenance – O&M-, investment, insurance, return on investment - ROI)
4. **Energy use and energy demand**, quantitative information of marine industrial sectors of the BE (i.e. up to date, historical, baseline data)
5. **Emissions** associated with each marine industrial sector activity of the BE (direct and indirect GHG sources, scope 1,2, and 3 emissions)
6. **Climate change policy framework** (i.e., sustainability energy targets, international commitment, mitigation/adaptation strategy)

Scope 1 emissions are direct emissions from sources owned or controlled by the organization (i.e. direct combustion sources, direct fugitive emissions). Scope 2 emissions are indirect emissions linked with electricity production, steam or heat imported for the activities of the organization. Scope 3 emissions are other emissions that are indirectly produced by the activities of the organization not included in Scope 2 which take place in the overall value chain (i.e. purchase of raw materials; employee commuting; upstream and downstream transport of products).

(Bilan GES, 2020).

The lack of information on the above written main concerns informs the objectives of this research. The aim is to identify market opportunities for ORE tidal and wave technology within identified maritime industries offshore.

2. Research Objective

There is limited knowledge on the benefits to implement tidal and wave technology in Australia, mostly because of the dominating growth of solar PV and wind power on the renewable energy market (Teske, 2018). With the pressure of climate change and sustainability agreements, Australia may face difficulties to satisfy the growing energy demand of marine-based industries. Hemer et al. (2018) write that ORE could exceed the current electricity demand and offers advantages that are complementary in a renewable energy technology portfolio (i.e. in combination with wind energy, solar energy, battery storage).

Information is needed to explain the status of ocean technology, involved costs and necessary regulatory support for sustainable development. Perceived capital and environmental risk need to be fully assessed to accurately address current assumptions and resolve the lack of data on the limitations and opportunities for ORE. The research sets out to fulfil the gaps of knowledge discussed prior. The following points are to be addressed and achieve the research aim:

1. Gain insight on ORE deployment, as well as current and foreseen commercial scale,
2. Identify the barriers, risks and opportunities for tidal and wave technology,
3. Quantify the energy usage, energy mix, and GHG emissions within marine industrial activity of the BE,
4. Understand the role of the BE, legislative decision makers, industries and technology developers toward the Sustainable Energy Transition (SET) in Australia.

The four points mentioned above shape the procedure and methodology for this thesis. The research will contribute to the larger scientific body of knowledge by gathering reliable information and relevant data on energy consumption, emissions, and the sustainability strategy of large scale marine sectors. The objective is to substantiate the proposal for a more sustainable energy system through a low-carbon resource input pathway and resulting emission abatement for Australia's overall energy system.

2.2 Research Question(s)

The main question this research seeks to answer is:

"What is the market potential for ocean renewable energy (ORE) in carbon-intensive industrial sectors of Australia's Blue Economy ?"

The market potential can be defined in terms of both technical and economic potential of ocean energy devices to reach commercial scale. The Ocean Energy Systems (OES), an IEA Technology Initiative, defines the commercial target as, "the first project that is constructed with a view to generate commercial return without the need for capital or public sector support outside of an authorized Feedin-Tariff," and does not represent the long term future cost reduction potential" (2012, p.5).

Three Australian industrial sectors were chosen for investigation:

1) Aquaculture (Section 3.4.1)
2) Oil & Gas (Section 3.4.2)
3) Ports & Maritime Shipping (Section 3.4.3)

In addition to the aforementioned industrial sectors, communication was solicited with ORE tidal and wave technology developer companies (section 3.4.4), as well as with representatives from energy/sustainability consultancies and organisations (section 3.4.5).

The method for selecting stakeholder representatives from BE sectors is found in the Sampling and Sector Inquiry Sections (4.2, 4.3).

2.2.1 Research sub-questions

T0 answer the main research question, the following sub-questions are investigated:

1) **What is the energy usage and carbon footprint of the target industrial sectors?**

Sub question one (SQ1) asks about the energy usage per company interviewed. First, the energy usage is interchangeable with the energy demand, energy consumption, or electricity purchased within an industry. Second, the emissions emitted by the company is investigated. The aim is to understand the relation between energy and emissions associated with a sector's activities, in order to identify ways to improve the resource efficiency and the carbon footprint within Australia's BE.

2) **What is the technical potential of tidal and wave energy of the identified industrial sectors?**

Sub question two (SQ2) researches the technologies' technical potential (defined in section 3.2), such as, the engineering design, the functioning, the power output and the site application of a tidal turbine or wave energy converter (WEC) device. The aim is to vision the current, near-term and long-term energy capacity (e.g. electricity, desalination) of ORE technology compared with the power demand of marine sectors inquired in SQ1.

3) **What is the economic potential of tidal and wave energy of the identified industrial sectors?**

Sub question three (SQ3) researches the technologies' economic potential (defined in section 3.2) by taking into account different cost factors relating to tidal turbines or WECs after considering the technical potential found in SQ2.

4) **What is a favorable policy landscape for innovation and development of tidal and wave energy in Australia?**

Sub question four (SQ4) seeks to understand the current Australian government framework and the necessary policy instruments for the transformation towards a sustainable energy system. The development of renewable energy sources (RES), particularly ocean energy, is complex and requires regulatory involvement and investment.

2.3 Relevance

The Energy and Materials track of the Master of Science (MSc.) in Sustainable Development offers an interdisciplinary perspective and transdisciplinary understanding of the current energy and material system and explores the opportunities for cleaner energy production options (UU, 2019). The research questions relate to the future global energy demand and the projected switch from fossil fuels and the role renewable energy can have in the energy system. Investigating the opportunities and barriers for the uptake of new innovative energy technologies and the policies needed to improve energy efficiencies and emission abatement are central topics explored throughout the study program and tie in well to the topic of investigation proposed here. Amongst the set of Sustainable Development Goals (SDGs), there are five goals that are most relevant to this research, notably goal number 7 which relates to affordable and clean energy, goal number 9 which deals with industry, innovation and infrastructure, goal number 13, which calls for climate action, and goal number 17, which incentivizes partnerships between governments, the private sector and civil society (UN, 2020).

3 Research Framework

3.1 Use of Research

This research is carried out in collaboration with the CSIRO, the Australian Ocean Energy Group (AOEG), the BE-CRC and Climate KIC Australia. The CSIRO supports innovation science and technology to solve current global sustainability issues (2019). The CSIRO plays an important role for the advancements of climate abatement targets and sustainable economic growth. The AOEG is non-profit industry-led cluster that fosters collaboration among actors of the ocean energy industry to work toward improving Australia's energy profile and resource mix (2019). The BE-CRC promotes innovation in marine focus areas with the aim to manage economic activity related to Australia's ocean resource in a sustainable way (e.g. sustainable seafood, RE production) (Voyer et al., 2017). Climate KIC Australia is a non-profit organisation that acts "as a catalyst for systemic change [...] to deliver transformational climate action" (2020, p.1). Climate KIC plays an important role as a supporter for the AOEG projects.

This research analyses three key industrial sectors with the highest potential to impact market uptake of ORE technologies with a view towards displacing the demand of fossil fuel based inputs. The quantitative and qualitative information that is to be retrieved can also be used by legislators for policy decision-making and setting appropriate national climate targets in line with climate change mitigation and adaptation commitments. The advancement in knowledge of ORE applied within Australia can build a baseline reference and serve as a pilot study for other coastal regions involved in pursuing ORE research and development (Appleyard, 2009).

3.2 Concepts

The Australian marine based industries (e.g. commercial fishing, oil exploration, boating infrastructure) are collectively referred to as the *Blue Economy* (AIMS, 2019b) (Table 8).

Carbon-intensive industrial sectors are defined as fossil-fuel dependent industries with a high energy demand for electricity, natural gas and diesel to carry out their activities within the BE. To illustrate quantitatively the energy demand of all industries[4] combined, in 2017-2018, the total consumption estimated per energy type was: electricity at 90,585 GWh, natural gas at 793.8 PJ[5] and diesel at 17,088 ML (ABS, 2020). These industries hold a large carbon footprint and have the opportunity to reduce their emissions by adopting a certain share of renewable energy throughout their processes.

[4] Mining, manufacturing, electricity/gas/water services, construction and transport/postal & warehousing

[5] 1 Petajoule (PJ) = 10^{15} Joules (J)

Fossil fuels include coal, oil, and gas. These accounted for 94% of Australia's primary energy mix between 2016 and 2017 (Australian Energy Statistics, 2018).

Energy intensity is a measure of the amount of energy needed to produce one unit of output or activity (Peters et al., 2017).

Ocean renewable energy (ORE) focuses on both wave energy and tidal energy, thereby excluding non-tidal ocean currents and ocean thermal energy conversion (OTEC). The focus on wave and tidal energy is because the CSIRO and AOEG, the collaborative entities for this research project, are specifically investigating these alternative forms of energy within industrial sectors.

The *technical potential* is the demand and energy savings that can occur if all operations or equipment is changed to a technically feasible level of energy efficiency. In other words, the technical potential is a more realistic estimate than the resource potential as it acknowledges system performance or infrastructure needed to extract the amount of energy and capacity that can be recovered by energy efficiency; however, the technical potential neglects economic barriers (Nadel, Shipley & Elliott, 2004; Brown et al., 2016). Technical potential of a renewable energy resource, is an estimate of the capacity (Megawatts), the potential annual generation (Gigawatt-hours) and the suitable land area needed for the deployment of RE technology (Lee, Flores-Espino, & Hurlbut, 2017). The measurement used for the technical potential, or potential energy savings is based on the electrical output, or gigawatt-hours (GWh).

The *economic potential* can be defined in several ways (Table 11).

Table 11: Economic potential definitions (Brown, et al., 2016).

Definition 1	$expected\ revenues - generation\ costs$ The expected revenues are based on local market prices.
Definition 2	$generation\ costs\ relative\ to\ a\ benchmark$ A benchmark can refer to a certain power plant (e.g., a natural gas combined cycle plant) based on general assumptions of fuel prices, capital cost, and plant efficiency.
Definition 3	$electricity\ generation\ costs < revenue\ available$ The revenue available relates to the displaced energy and displaced capacity values.

3.3 System Boundaries

The boundary set for this research considers the BE geographic system, that is offshore and nearshore activities. As such, the selected industrial sectors and inquiry on their energy system relates to activities taking place at the location, in Australia, thereby excluding energy associated with transport or transmission from the location to the end-consumer or customer.

This research relies on the hypothesis that ORE is a potentially viable alternative for energy demand and energy use given the resource and knowledge potential within Australia's BE.

Through technological innovation and investments in tidal and wave technology, progress towards sustainability goals can be made within large maritime industries. The ORE technologies considered in this research are tidal and wave as these are the research and development priorities of the host organisations (CSIRO, AOEG). Non-tidal ocean flow - ocean thermal and offshore wind are not included in the scope of this thesis because current projects and research in Australia are in tidal and wave energy. Otherwise there would be insufficient information to compile a precise literature review relevant to the country and the focus areas of the BE CRC.

The energy system boundaries considered for Aquaculture was defined by the available literature information on the various equipment for operations and facility systems. Main infrastructure can be grouped to include water, air and electrical systems, production space and support spaces. This research seeks to gain quantitative information on the electrical system (i.e. lighting, feeding, pumping) and the production space (i.e. incubation, juvenile, grow out) thereby excluding support space (e.g. feed storage, equipment storage, supply storage, packaging areas, transfer facilities), air and water systems (i.e. filtering, oxygen dissolving) (Held, n.d.). The reason to exclude support space is that is in the transformation value production chain, and the investigation is looking at the production stage of the value chain to limit calculations needed to account for transport energy. Air and water systems are complex and large energy demand areas, so for simplicity are not included.

The primary O&G industries investigated are limited to those located offshore to be within the geographic bounds of the BE. The energy system considered was limited to the production and own use of the O&G company. The energy need for transformation and transmission was not investigated. All Ports in Australia were considered with a priority for those located within tidal range or wave opportune areas. The energy system considered was limited to the Port's (on land) location.

3.4 Literature Review

3.4.1 Aquaculture

Background
Aquaculture is the farming of aquatic organisms and is becoming more globally interconnected as fish becomes one of the most traded commodities (Madin & Macreadie, 2015). In the ten years between 2006-2017 aquaculture products grew by 53% in volume (ABARES, 2019). Aquaculture production focuses on high value export fish, where the three most valuable aquaculture species in 2017-18 were salmonids, tunas and oysters accounting for 62%, 9% and 7%, respectively, of Australia's production value (Table 12). The IBIS world (2017) confirms that there is a strong demand for premium products such as salmon that continue to support the growth of the industry. There is a 'blue growth' focus on social, economic and environmental impacts of aquaculture activities. Dempster and Sanchez-Jerez (2007) suggest that offshore production can mitigate the competition for space allocation in coastal waters but needs to be implemented at a large scale to moderate costs and to remain competitive. Ward (2011) confirms that at sea cages for fishing culture is one of the fastest growing methods in the aquaculture industry.

Table 12: Australian top three aquaculture industry species by monetary value (ABARES, 2018).

	Salmonids	Tuna	Oysters
Monetary value (AU$ million)	855	126	102

There are three main types of commercial industrial aquaculture production systems: extensive, semi-intensive and intensive (Table 13). In the scope of this research the production method observed falls under an intensive practice, which involves tanks, ponds in open water and the culture of carnivorous fish (e.g. salmon) (Kime & Harper, 2019). This research assumes an intensive production systems and includes cage and pond culture, recirculating aquaculture systems, and flow through systems for the three case study companies (VFA, 2020).

Table 13: Operational aquaculture systems ranging from semi-extensive to super-intensive (Muir, 2015).

			Energy inputs per tonne of production		
Term	**Definition**	**Tonnes /ha/year**	**GJ per annum**	**Tonnes fuel equivalent**	**Species**
1) Semi-extensive	limited cage system	0.5 - 5	25	0.5	lower-value detrivorous, carnivorous and omnivorous (e.g. tilapia, carps)
2) Semi-intensive	food produced within culture environment, usually fertilized	2 - 20	50	1.0	
3) Intensive	completely fed, ponds and tanks	100	75	1.5	higher value (e.g. salmon, turbot, sea bass)
4) Super-intensive	completely fed and tanks	1000	100	2.0	

**Note: equivalent tonnes of fossil fuels is used to maintain term consistency and reference measurements. Fuel equivalents at 40 GJ = 1 tonne diesel.*

Economic Significance

The commercial aquaculture industry generates around AU$2.4 billion annually and employs over 10,500 people (Austrade, 2015). In 2017-18 the Gross Value Product (GVP) of the aquaculture industry contributed AU$1.42 billion (ABARES, 2020). Table 14 displays the economic contribution of aquaculture specifically, to Australia in the year 2017-2018. The total direct gross value added (GVA) amounted to AU$1,692 million from production, and AU$330 million from processing (ABARES, 2019). Aquaculture increased by 4% in volume to AU$3.18 billion in 2017-18 (ABARES, 2018). The costs of production vary based on the species that is farmed, the scale and intensity of production (Irvin et al., 2018).

Table 14: Economic contribution (Gross Value Added and Gross Value of Production) of aquaculture to Australia, 2017-18 (BDO EconSearch, 2019, p.71).

	GVA (AU$M)	**Employment** (FTE jobs)	**GVP** (AU$M)
Direct contribution of			
Aquaculture production	623	5,155	1,457
Aquaculture processing	93	978	213
Total Direct	*716*	*76,133*	*1,870*
Indirect contribution of aquaculture to all other sectors			
Production induced	507	4,590	-
Consumption induced	827	362	-
Total Indirect	1,334	10,952	-
TOTAL	**2,050**	**17,086**	**1,669**

In Australia, there are multiple aquaculture industries that are guided by strategic action agendas set by the National Aquaculture Development Committee (FAO, 2020). There are nine Australian Security Exchange (ASX) listed aquaculture stock companies that contribute to seafood production, of which three are represented in the research, notably Tassal, Huon and Petuna (Yeo, 2018). Tassal and Huon dominate the Australian aquaculture industry with 25.8% and 11.7%, respectively; Petuna makes up 4% of the market share but is unique because it is a private company while Tassal and Huon are family owned (Capitalistic Man, 2019). The estimated market capitalisation for Tassal is AU$885 million, for Huon is AU$394 million and for Petuna is estimated at 27.7 million (Capitalistic Man, 2019).

Industry Operations

Australia is recognized for producing sustainable aquaculture products and is an industry that is experiencing rapid growth in the state of Tasmania (Huon Aqua, 2017). “Tasmania is the heart of the aquaculture industry in Australia” contributing close to 60% of the country’s total production (IBIS World, 2017). ABARES (2018) further states that in 2017-18, salmonids made up 96% of production value in Tasmania.

The major aquaculture companies investigated in this research include Huon Aquaculture, Petuna Aquaculture, and Tassal Group, henceforth referred to as Huon, Petuna and Tassal, respectively. The three aquaculture enterprises are located in Tasmania, mainly produce salmon (Norwood, 2018; Table 15).

Table 15: Total volume production of three major Tasmanian aquaculture companies from 2017 to mid 2020 (Tasmanian Salon Farming Data, 2020).

Fiscal Year	**2017-18**	**2018-19**	**2019-20 (Mid)**
Company		Production (tonnes)	
Tassal Group	29,306	32,157	17,628
Huon Aquaculture	23,681	18,818	13,677
Petuna Seafoods	7,058	6,013	3,738

Case study companies
Three Aquaculture companies were selected for case study analysis and are listed below in decreasing order of size and value. The companies were selected based on their significant size and economic contribution to the sector as well as the communication network with AOEG. Tassal was the only company out of the three investigated that was available for an interview. To answer both the research and interview questions precisely, additional information was found through the literature.

1. Tassal Group
2. Huon Aquaculture
3. Petuna Seafoods

See Annex 1 for description of each company selected for the research/interviews.

3.4.2 Oil & Gas

Background
The Oil and Gas (O&G) industry is one of the most active sectors in the Australian economy with the largest volume outputs being fuel, oil and petroleum. The demand for hydrocarbon energy, which forms the basis of fossil fuels, is high due to the human dependence on petroleum-based products and materials (e.g. LNG, LPG, gasoline) (Parekh & Singh, 2015).

In 2017-18, Australian energy consumption of all sectors was close to 6,200 PJ, with electricity supply accounting for 26% (Dept. Envr. 2019, p.19). In 2017-18, there was a significant growth in energy consumption for the mining of oil and gas due to a higher demand for LNG domestic use (286 PJ) and LNG exports (from 52 62 million tonnes) (Dept. Envr., 2019, p.23).

O&G facilities are located offshore and rely on vessels such as AUVs (automatic underwater vehicle), ROVs (remotely operated vehicle) and AHTs (anchor handling tug) with advanced operating systems and modern technology to provide services (Guardian Offshore, 2020). The equipment used for production includes pumps, compressors, motors, turbines, engines and heaters (Vanner, 2005). The vessels that provide the services in offshore water have a support network with shore-based facilities. The services offshore range from a variety of activities such as drilling, maintenance and repair services and provision of fuel and fresh water. Supply operations include pipe laying and providing rigs with drilling material (Guardian Offshore, 2020).

Economic Significance
Australia develops energy sources, especially LNG for export (Gunn, 2014). In 2018-19 the O&G industry increased to AU$34.5 billion, a 19% increase in GVA from the previous year, due to the growth of new LNG facilities (Watts, 2019). There is a year to year increase in total energy production due to the rise in natural gas production (Austrade, 2020). Australia's LNG export volumes are forecast to rise from 75 million tonnes in 2018-19 to 81 million tonnes in 2020-21

with a declining real value, AU$51 billion, to AU$49 billion and AU$4 billion from 2018-19, 2019-20, and 2020-21, respectively (Dept. of Industry, 2020). Oil export earnings are estimated to peak in 2021-22 at AU$11 billion then decline to about AU$9.6 billion in 2024-25 (Dept. of Industry, 2020).

Industry Operations
O&G production requires large amounts of energy throughout the value chain from extraction to processing and product export. The supply chain includes production, transformation and transportation, where about half of all energy consumed is in the transformation process (IPIECA, 2007). Given the international and nation economic significance of the sector, operations run around the clock, all year round. The main management strategy is to optimize processes to avoid any risk of downtime (Vanner, 2005). Murray (2019) sites three main potential offshore systems relevant in O&G asset operations (Table 16).

Table 16: Offshore asset and system description in Australia's O&G industry (Murray, 2019).

Offshore asset	Description
Remote subsea power	Offshore monitoring with metric and sensors for developments and long-term observational studies.
AUV/ROV charging stations	ROVs need to be recharged and operated from a removed location. Avoids cost of vessel mobilization.
Subsea power and control systems	O&G systems require power to control and carry out operations (e.g. valves, pumps).

Case study companies
Five O&G companies were selected for interview and are listed below. The companies were chosen based on their large-scale activity in Australia. Individual interviews were held with three of the five companies, considering there are about 30 major O&G companies listed on Australia's stock exchange (ASX). To answer both the research and interview questions precisely, additional information was found through the literature.

1. Arrow Energy
2. A Top 5 ASX O&G Company
3. Carnarvon Petroleum Limited
4. Conoco Phillips Petroleum
5. Woodside Energy

See Annex 2 for description of each company selected for the research/interviews.

3.4.3 Ports

Background
In Australia, maritime infrastructure plays a vital role in supply chain activities. Port transport systems allows the country to export domestic freight and bring in a large volume of goods from overseas (Ports Australia, 2019). A port is a marine facility that usually has one or more wharves

used to dock ships for unloading of cargo. As an island, the country is dependent on shipping for coastal trading (Dep. Infrastructure, 2018).

Economic Significance

The total throughput across all states and territories, for 48 selected ports, in exports was more than one billion tons and the value of cargoes stood at over AU$40 million in 2018-19 (Annex 13, Table AC).

Industry Operations

In Australia, the majority of ports are government owned and operated under the port authorities oversight (Dept. of Trans., 2020). There is sustainability management and master planning that guide activity development. Port facilities service and connect a wide range of customers (e.g. fuel tankers, cruise industries and commercial vessels) (Ports Australia, 2020). Australia holds some of the largest multi-cargo ports and enables the transportation of a diversity of commodities ranging from livestock and grain, to minerals and fuel. There are different types of vessels that contribute to the transport activity, ranging from dry bulk with up to 3999 TEU* to bulk liquid with over 9000 TEU container vessels capacity (Table 17).

Table 17: Vessel calls by capacity and number in FY2018-19 for 48 selected Australian ports (Ports Australia, 2020).

Commercial vessel calls by capacity	Number of Vessels
Number of container vessels up to 3999 TEU	2,413
Number of container vessels up to 4000-5999 TEU	1,811
Number of container vessels up to 6000 - 7999 TEU	426
Number of container vessels up to 8000-8999 TEU	75

**TEU is Twenty-foot Equivalent Unit (i.e.20ft long, 8ft wide, 8ft tall capacity) for a shipping container (Freightos, 2020).*

Table 17 indicates that the majority of vessels passing through ports are those with smaller sizes (i.e. ranging up to 6000 TEU). The smaller capacity may suggest a lower energy use when docked at the port than the container vessels measuring 6000 TEU or more; However, the larger flux of activity would then amount to a significant overall energy demand per year. Usually diesel is the source of power when vessels pass through, so there is the opportunity for alternative low carbon sources. The data on Ports Australia shows that the majority of commercial vessels are those trading dry bulk and containers (2020).

Case study
Five ports were selected for case study analysis. The ports were chosen based on the active reply of target stakeholders and are as follows:

1. Port of Brisbane: PI
2. Port of Broome: PB
3. Port of Esperance: PE
4. Port of Gladstone: PoG
5. Port of Townsville: PT

See Annex 3 for description of each company selected for the research/interviews.

3.4.4 Ocean Technology Developers

Background
Technologies to capture ORE are mostly in their infancy stages with a few in commercial deployment; Simon (2019) highlights that the production of ocean-sourced energy generates among the lowest CO_2 emissions especially when taking into account that wave energy is much more dense than solar energy. The development of ORE is a complex issue as it involves policy and legislation, an international market, social acceptance, and disruptions to the physical environment.

Economic Significance
Government agencies have invested millions of dollars into wave and tidal resource development in Australia. For example, ARENA funded AU$2.49 million for Tidal Energy Project 2020, the BE-CRC is providing AU$858 thousand for research in integrated offshore aquaculture and RE infrastructure design as well as identifying synergies for emerging blue industries and offshore energy (2020) (Table 7).

Operations
Partnerships have formed between research centers (e.g. AIMS, BE-CRC, CSIRO), technology companies (Table 18) and the government to fund projects and negotiate commercial opportunities surrounding ORE that are growing in Australia. Carnegie confirms, "extracting energy from the global wave energy resource is the objective of governments and companies alike but the technology to achieve this at a sufficiently low price has remained elusive" (2020, pg.1). For example, a project for tidal energy was awarded AU$2.49 million to map the country's total tidal energy sources (AMC, 2017). The project is led by the Australian Maritime College (AMC) in partnership with CSIRO and University of Queensland. The goal is to make publicly available data on the risks and possibilities of tidal technology and communicate with potential investors as a way to advance the commercial scale of ORE (AMC, 2017).

Table 18: Australian wave and tidal developers known to the European Marine Energy Center (EMEC) (2020).

Company Name	Device Name
Wave Energy	
1. AMOG	AEP
2. Aquagen Technologies	Rig Drive
3. BioPower Systems Pty Ltd	bioWave
4. Bombora Wave Power	mWave
5. Carnegie Wave Energy Ltd	CETO 6
6. Marine Power Technologies Pty Ltd	Energy Island
7. Perpetuwave	Xtracta (Hybrid Attenuator)
8. Protean Wave Energy Ltd	Protean WEC
Tidal Energy	
1. BioPower System Pty Ltd	bioStream
2. Cetus Energy	Cetus Turbine
3. Elemental Energy Technology Ltd	SeaUrchin
4. MAKO Tidal Turbines	MAKO Tidal Turbines
5. Tidal Energy Pty Ltd	Davidson Hill Venturi Turbine

Case study companies

Five companies that were selected for case study analysis and are listed below. The companies were chosen because they are of Australian origin, have commercial related activities implanted in Australia, and based on the communication network with AOEG. To answer both the research and interview questions precisely, additional information was found through the literature.

1. Bombora Wave energy
2. Carnegie Clean Energy
3. MAKO Tidal turbines
4. Sabella
5. Wave Swell Energy

See Annex 4 for description of each company selected for the research/interviews.

3.4.5 Consultancies

Case study companies

Interviews were held with three consultancies and an industry growth centre. For simplicity and organisation of the writing, the industry growth organisation National Energy Resources Australia (NERA) is grouped as a consultancy given its role to foster collaboration.

The companies were chosen because of the established communication network with AOEG and are as follows:

1. NERA
2. ATTERIS
3. ORE Catapult
4. Pitt&Sherry

See Annex 5 for description of each consultancy selected for the research/interviews.

4. Methods

4.1 Methodological Approach

This thesis follows a mixed-methods approach by combining qualitative and quantitative research tools, notably an in-depth literature review and expert interviews. The information obtained from scholar published journals and interviews with stakeholders (i.e. industries, technology developers, consultancies) serves to build an understanding of the potential for installing of tidal and wave technology within marine sectors of the BE region of Australia. The interviews seek specific information on the energy system, emissions, sustainability approach to renewable energy and ocean energy. Individual companies represent an industrial sector. Conversations with technology developer companies are to gain insight on target customer profiles and market approach to what extent the industrial sectors could fit as a potential client. Discussion with consultancies and government representatives serve to have an outside perspective on the energy supply and demand market ecosystem comprised of technology developers (as alternative low-carbon energy providers) and industrial sector companies (as potential low-carbon energy consumers). Data processing was organised and analysed in Excel for each sub-question and industry sector. An overview of the methodology can be found in Annex 15.

The investigation began with a scoping study of a subset of marine industries and economic activities involved in the BE in Australia (Table 19).

Table 19: Marine related activities and sub-sectors in 2015-16 (AIMS, 2018, p.7)

* Recreational fishing	* Marine equipment retailing
* Commercial fishing	* Boatbuilding & repair
* Marine-based aquaculture	* Marinas and boating infrastructure
* Natural gas	* Domestic consumption of tourism goods & services
* Oil production	* International consumption of tourism goods & services
* Oil exploration	* Water-based transport of passengers & freight
* LPG: liquefied petroleum gas (offshore oil & gas extraction)	
* Shipbuilding & repair	

The sub-sectors relevant to the scope of this research are highlighted in grey in table 19.

The first boundary of the research is set by researching economic activities based offshore in order to align with the geographic locations of available ocean resources, specifically tidal stream and wave energy. Sustainability objectives for emission reduction and climate mitigation are putting pressure on land use and land development that is needed for industrial activity growth.

Given Australia's island geography and strategies for SET, the focus of the research is placed on offshore generation and consumption as opposed to onshore. In this case ports are considered because they are a foothold for offshore economic contribution from traded commodities. For example, there is a growing demand for land area for the expansion of wind and solar technology, which are more commercially advanced and so may take priority in the system involved for grid connection (IEA, 2020). The benefit of focusing on offshore is that the infrastructure of the selected companies is in place and ORE devices can be directly linked to provide the energy that enables activity. In the initial stages of ORE development and implementation, the costs of placing additional infrastructure (e.g. transmission cables) for tidal and wave capacity onshore are likely to be postponed until ORE technology reaches a more advanced maturity and experience offshore to be applicable to the mainland grid system - a potential theme for future research. Efforts are made to contribute to the current body of knowledge and research on ways to expand marine activity from nearshore to offshore, to improve energy efficiency within offshore industries and to promote the contribution of ORE in Australian marine businesses.

The Australia Institute of Marine Science report and the Remote Ocean Power Enabler (ROPE) project help to provide an overview of marine industries (AIMS 2018; Murray, 2019). The AIMS collects economic data and forecasts the contribution of Australia's marine industries to the Blue Economy (AFMA, 2015). The ROPE project produced a criteria-based assessment to evaluate the market potential of ORE for different industries (Murray, 2019; Table 20).

Table 22: Appendix A – pg. 11, 12, & 13 taken from the ROPE Phase 1 Final report: Assessment of power requirements and market potential of ORE to direct the selection of industrial sectors for this research investigation (Murray, 2019).

	Aquaculture	O&G	Power
Description	**Offshore fish farms:** power for remote monitoring equipment and feed systems.	**Remote subsea monitoring**: Lighting, observational studies. **AUV/ROV charging stations:** operated from remote location, avoid costly vessel mobilisation. **Subsea power & control systems:** power to monitor operations valves.	**Isolated communities:** Access to; reliable, cheap renewable power. **Remote island power:** island require off-grid power via locally operated generators or renewable power.
Working environment	<60m, max velocities 0.7m/s average flow velocity <0.2 m/s	Variable depths 0-2000+m, current speeds vary within water column	<10 m
Power Requirements	<200 W (lighting systems) ~10kW	<10 kW for remote monitoring & AUV/ROV stations <500 kW for subsea power & control systems	<100 kW
Market potential (MP)	**Offshore fish farms:** medium (2) MP with interesting opportunities, flow velocities are often low but if located nearby fish farm would be viable option.	**Remote monitoring:** high (1) MP because target market example since other markets with similar architecture could use tidal technology in future once it is proven in the sector. **AUV/ROV stations:** medium (2) good MP but requires other technology development to be realised, so future potential market. **Control systems:** low (3) MP because power requirements are so high, it is not a suitable target market	**Communities & islands:** Low (3) MP because necessary power requirements would suit a higher flow power turbine.

The table above ranks the market potential for tidal and wave energy within three different offshore activities mainly drawn from the working natural environment and power requirements associated with each sector.

Based on information provided by each reference on various sectors, a primary selection of five marine sectors is made, and can be found below:

- i) Aquaculture & fisheries
- ii) Offshore oil and gas (O&G)
- iii) Ports, marinas, and ship building
- iv) Microgrid islands, communities
- v) Ocean observation and monitoring

The member network and communication hub established by AOEG is used as a primary sampling pool to reach out to sector representatives. Then, based on the active response rate of related stakeholders, the final choice of target sectors for case study research is established and is as follows:

1) Aquaculture
2) Offshore O&G, hereafter referred to as O&G
3) Ports

The narrow selection of industries is made in order to research the specific value chain activities that entail an energy demand and carbon footprint. The fisheries sector is distinguished from the aquaculture sector and is excluded from the research boundary to focus only on commercial, large-scale based activity. Onshore O&G are avoided because their activity relies on grid-connected energy sources, so it is very unlikely ORE can serve as an input in the time frame bound by the research (i.e. by 2030). Marinas and ship building are excluded from the boundary in order to focus on industrial-based flux of activity rather than small scale, individual boating and transport activity. Microgrid islands are not included in this research first because of the low market potential score analysed by Murray (2019) and the scale of energy demand is comparatively small (i.e. Aquaculture, O&G, Port). The different economic scale between the chosen large-scale industries and microgrids would make it more difficult to draw a cross-sector relative comparison of (quantitative) data. Ocean observation and monitoring is not included in the scope of this thesis because most knowledge of this activity is limited to the United States (OES Environmental, 2019). Therefore, more information would be required and specific to Australia for a case study analysis of the aforementioned sector.

Another reason for the three industries selected is the hypothesis that for tidal and wave power generation to make a significant contribution to Australia's energy mix, sectors with a significant energy demand (i.e. hundreds of gigajoules) would generate better return on investment. Technology developer companies and consultancies were also interviewed to have an understanding of both sides (supply and demand) for establishing a market analysis for ORE penetration in Australia's BE.

As the ORE industry is more advanced in Europe, this research draws on the experience of European technology developer companies which can serve as an example for Australia, for whom R&D and commercial scale for tidal and wave technology are less advanced. The time period in this research seeks to consider the past from 2015 and a future year mainly until 2030. The 15-year time frame is used to prospect ORE technology progress and also aligns with national sustainability targets as well as a substantial amount of international climate scenarios.

4.2 Sampling

Convenience sampling was followed, meaning research is carried out with members of the population who are available to the investigator (Naderifar, Goli & Ghaljaie, 2017). The sampling follows a random and snowball technique. Random sampling is where each sample has an equal probability of being chosen; Snowball sampling is used in a context where access to subjects is difficult so existing study interviewees help to connect with future interview targets (Naderifar et al., 2017). The sampling size was set at a minimum of three companies per industrial sector to obtain a potential spectrum of expertise and opinions. The sample is intentionally short of representing the entire maritime sectors and the BE, recognizing that further interviews with stakeholders and additional research would provide better precision and accuracy of results.

The social media network LinkedIn was used both to identify and contact stakeholders. Representatives were selected based on their field of expertise and level of experience with the following keyword search categories:

Environment* manage*
Development manage*
Commercial manage*
Environments/environmental
Manager/management
Sustainability advising OR consulting
Experience in renewable energy* technolog*
energy/energies
technology/technologies
Experience in infrastructure project
Enginee*
engineer/engineering
Business innovation OR strategy
Project develop*
developer/development

The asterisk is used to mark the various possible endings of the key words searched, the full words are exemplified in italics. Emails were sent to a minimum of two and up to six key employees within each identified company. The written email introduced the research participants, a description of the research, the aim for carrying out the interview, and a proposed potential time and date for a semi-structured conversation. Semi-structured interviews are chosen to provide a direction to the conversation and open-ended questions while allowing answers to be steered by the interviewee; this way opinions can more easily be shared from the perspective of the interviewee and the potential researcher's bias is minimized.

Consent was asked prior to carrying out the interview and confirming that anonymity of the interviewees name was granted throughout the report. Anonymity was also honored in the case where an interviewee representative wanted the company name to not be mentioned in writing. After each interview, a detailed summary was written and sent back to the interviewee for review to make sure the recorded information was accurate and for any necessary changes to be made prior to including in the research analysis. Once the interviewee sent back his or her edited version of the interview summary, the document was sent to the internship supervisor for additional review.

A total of 19 interviews were completed, beginning from January 30th up until June 12th, 2020 (Annex 6). A summary of interview responses can be found in Annex 8.

4.3 Sector Inquiry

This section goes into further detail to describe the sampling method and objective for inquiring the selected representative sector of the BE.

Once all interviews were completed, a concise summary was written to be more easily integrated into the research for analysis of the discussions themselves and in drawing similarities and differences with the research literature information.

4.3.1 Aquaculture

The aquaculture sector is chosen for investigation because the BE CRC is dedicating research to find efficient energy pathways for fish production offshore (2019a).

Objective
Australia holds the third largest fishing zone globally, with about 60,000km of identified coastline and is recognized internationally for its seafood quality and standards (DPI, 2019). Offshore installations of aquaculture operations are becoming more widespread to meet the growing international and national demand. The expansion of infrastructure and equipment offshore provides an opportunity to integrate ORE as an energy and electricity source for aquaculture operations. The aim of the interview is to obtain specific information related to the company's current energy usage, electricity demand, and emission reduction strategy. The interview also seeks to know about the knowledge held and appetite for alternative non-conventional energy pathways.

Sampling
The method for selecting stakeholders from the aquaculture sector was based on the professional connections of the Principal Research Scientist at CSIRO and the Cluster Manager at AOEG. Further contacts were chosen by searching among industry and expert partners in the BE-CRC.

4.3.2 O&G

Objective
The O&G sector holds high potential for tidal and wave energy installations because a large part of the industry's value chain operations take place offshore, an opportune geographical area for ORE technology development. CSIRO Futures (2017) confirms that over 80% of Australia's oil and gas resources are in offshore areas (p.57). In addition, the ROPE assessment indicates the O&G sector, specifically remote subsea monitoring, as a high market potential for ORE because the architecture in place could be used for tidal technology (Murray, 2019, p.13). Secondly, AUV/ROV charging stations nearby O&G platforms hold a medium market potential because of power requirements estimated at less than 10 kilo Watts per system – there is need for further technology development to secure the market (Table 20).

The O&G industry is a key economic contributor to Australia, but remains energy intensive because it is driven by fossil fuels. The O&G sector is chosen for this investigation because there is limited data on fuel gas use and models to help understand various input and output stream of process systems (Vanner, 2005). There is limited quantitative information that specifically relates to the energy consumption per industrial sector investigated in this research. Available energy statistics fall under broad categories of industry (e.g. construction, transport, manufacturing) making it difficult to distinguish at the sub-sector level.

Australia is investing billions of dollars in developing O&G projects (Nicholson, 2019). The possibility to redirect and strategize the monetary sums towards efforts in sustainability makes a good case for this research to explore the type of collaboration needed with decision-makers to enable renewable energy adoption.

Sampling
An online Google search was done to identify the largest offshore and O&G industries in Australia in combination with the information provided by Nicholson (2019) on the upcoming O&G development projects in Australia (Annex 11, Table R). One company was referenced by an AOEG colleague, and a few other companies were suggested by an interviewee.

4.3.3 Ports

Objective
There are over 50 ports in Australia and these play a vital role in supply chains. Marine infrastructure offers a significant opportunity to integrate tidal and wave technology and contribute to lowering the carbon footprint. Several ports are advanced in sustainability initiatives for renewable energy, but there is a need to increase communication and knowledge across the sector specifically surrounding ORE. The aim of the interviews is to understand the energy demand and commercial activity of the ports, to ultimately inform industry actors as well as technology developers and forge the pathway to integrate ORE technology.

Sampling
The primary selection of ports targeted for interviewed was based on AOEG's client and participant network. The remainder of ports chosen for interview were selected based on their geographical location and suitability (e.g. tide ranges, currents) to install ORE technology. Another criterion was the presence of a designated representative in sustainability or environmental management at the port. In addition to the LinkedIn platform, potential stakeholders were searched for on team page of the port's website.

4.3.4 Technology Developers

Objective
The motive to reach out to technology developers is to gain direct insight on the current methods of development and commercial progress of the devices. While technology developers are aware

of their target market and potential customers, a knowledge gap remains to achieve competitive scalability and meet the needs of large-scale energy consuming industries (e.g. Aquaculture, O&G, Ports).

Sampling

The selection of technology developer businesses (i.e. Bombora, Carnegie Clean Energy, MAKO, Sabella and Wave Swell) for the research was based on AOEG's consortium members and the target individual's agreement to participate in an interview (excluding Carnegie). Contact was made with AOEG's cluster manager to gain access to the emails of the company representatives. Further contacts were chosen by identifying speakers in subject-relevant conferences and summits such as: The International Tidal Energy summit 2019, the European Wave and Tidal Energy Conference (EWEC), the International Conference on Tidal and Wave Power (ICTWP) and the International Conference on Ocean Energy (ICOE).

4.3.5 Consultancies

Objective

A few consultancies were contacted in order to expand the breadth of knowledge on the opportunity or difficulties present for commercialising ORE as a source of energy in Australian industrial marine sectors. By speaking with a larger network of industry representatives and involved government agents, the strategy needed for collaboration between wave and tidal technology companies and target customers can be better developed.

Sampling

The industry representatives that were contacted were identified based on AOEG's network membership and the industry participants listed on the BE-CRC page. Four stakeholders were interviewed, namely: an engineer from ATTERIS, the general manager from NERA, and consultants from ORE Catapult and Pitt&Sherry.

4.3.6 Government

An interview was carried out with a consortium member of AOEG that has experience in government and policy.

Objective

The objective of the interview is to gain insight on the policy framework and storyline for renewable energy in marine industrial sectors of the BE in Australia. The aim of the interview is to answer SQ4 with precision and up to date knowledge of the situation, for which information is limited in the body of literature.

4.4 Data

In the scope of this research the energy usage referred in SQ.1. is determined based on the electricity and other energy sources (e.g. diesel, petroleum, renewables) when applicable. The technical potential asked in SQ.2 is determined as the theoretical share of electricity or current fossil-fuel based energy source that can be replaced by tidal and/or wave energy.

4.4.1 Literature Data

An important source of information is the reporting from AIMS – Australian Institute of Marine Science- Index of Marine Industry reports demonstrating the contribution of marine industries, with the fastest growth of the BE in 2015-2016. The AIMS is the central tropical marine research agency that researches Australia's marine industries and provides information on sector related activity (AFMA, 2015).

To answer SQ1, latest up to date, when available, sustainability reports were reviewed in detail for all three industrial sectors. Since quantitative information in reports is rather limited, interview responses were used to complement the missing information.

To answer SQ2 and SQ3, company annual reports, media news publishing (e.g. demonstration/deployment projects), government information, and company website pages were reviewed. Responses from interviews carried out with technology developer company representatives were used to estimate more precisely the numerical values needed to measure the technical and economic potential.

To answer SQ4, legislative bodies, organisations and policies were looked at in Australia, and in Europe, as Europe is more advanced on the ORE front. Opinions from interviews held with organisations or institutions were used to obtain present information and help to envisage realistic scenarios.

4.4.2 Observational Data

Carrying out interviews was important to gain specific insight on the energy consumption, carbon footprint per industry sector and the company's mindset on integrating sustainable practices, technologies as well as achieving energy improvement throughout operations. A summary of interviews can be found in Annex 6.

A series of questions were asked to the interviewee representative within the BE (Annex 7). The questions were kept as identical as possible to maintain consistency, though a few questions were adjusted to better suit the context of the sector.

5. Results

Results are displayed in order of each sub-question. To maintain a consistent time period and organized display of data, results for all sectors try to be kept from 2017 to 2019, and 2020 when data is available. The three-year time period is helpful to extrapolate results and trends for 2020. This way comparisons can also be made between sectors within a recent time frame of economic activities and political decision making. Data for previous years can be found in Annexes 10-13. Two decimal points are kept to present numerical data.

5.1 Energy use and carbon footprint (SQ.1)

In cases where numerical data was not available, energy use calculations are based off one company's energy consumption and energy mix data for the latest year possible. In some cases, averages are taken between two or more years or between different literature sources to reduce outliers.

Emissions per sector are calculated based on the two emission factors, 51.4 kt CO_2 per GWh and 66.9 kt CO_2 per GWh to create a lower limit and upper limit, respectively, for carbon emission abatement potential (Dept. Envr., 2017). The low end and high-end emission factors are an average of natural gas combustion fuels and liquid fuels combusted, respectively (Annex 14). Emission abatement is based on the displacement of fossil fuel based electricity input with ORE technology, estimated as a null emission output since it is a renewable source. Then, the calculated ORE power generation potential (in GWh) is used to calculate the emission abatement in kiloton carbon dioxide (kt CO_2) (equation 1).

Equation 1: Emission abatement potential per sector for electricity use.

$$CO_2\ abated\ [kt] = ORE\ potential\ [GWh] *\ emission\ factor\ \left[\frac{kgCO_2}{kWh}\right] * \frac{10^6 kWh}{Gwh} * \frac{1\ kt}{10^6 kg}$$

5.1.1 Aquaculture

This following section seeks to answer sub-question 1 respective to the Aquaculture sector of the BE, with quantitative and qualitative data. The information combines literature sources and responses pertaining to the following interview question:

i) How important are energy costs and needs in Aquaculture?

Energy

Limited to no data is available for Petuna so answers mainly represent energy use from Huon and Tassal's. Direct energy inputs to aquaculture operations include: collection production of juveniles, general operations of the system, harvesting processing and transport of the product (Troell et al., 2004). The bulk of energy demands come from feed barges, for storage and distribution of feed to the pens (all of which are operated using diesel generators). Factors that can influence the energy use are location in relation to sea level and influence from low and high tide (Hornborg & Ziegler, 2014). Muir (2015) writes that feed provisioning is about 80% of energy production for fish cultivation.

The interviewee representing Huon explains that growing fish at sea requires a fleet of vessels which runs on diesel fuel; However, there are no eminent barriers to energy consumption because diesel is available (Environmental Compliance and development manager, personal communication, May 5, 2020).

The production volume is used to calculate the energy use and energy inputs for each of the aquaculture companies (Table 22, 24). Two literature sources are referenced for energy calculations. First, the energy demand ratio of 14.34 GJ/HOG tonne proposed by Hemer (2019) is used because it is recent and available data on the production volume (in HOG tonne) (Table 21). Second, the energy demand ratios reference by Troell et al. (2004) is used as an additional literature source for comparison (Table 23).

Table 21: Production volume in HOG (head on gutted weight of fish) for Australian Aquaculture companies (Tasmanian Salmon Farming Data, 2020).

	Production volume (HOG tonnes)			
Company	**FY 2017/18**	**FY 2018/19**	**FY 2019/20**	**FY20 Extrapolated**
Tassal	29,306	32,157	17,629	35,258
Huon Aquaculture	23,681	18,818	13,677	27,354
Petuna	7,058	6,013	3,734	7,477

Table 21 shows there is a positive growth trend in the production volume for each of the three aquaculture companies in the past three years. Please note that the FY 2019/20 column accounts for production until the middle of this year, so the volume estimated in the last column is calculated based on double the production volume reported in FY2019/20.

The growth trend is difficult to estimate because production volume in the FY2019 for Huon and Petuna was lower than the previous year. Furthermore, the values for the following year are only until the middle of the year 2020, so the energy values for FY2020 are estimated as double that of the value shown for FY2019-mid2020. In this case, the suggested increase in volume can be calculated from FY2018 to FY2020 but may be an overestimation.

Table 22: Extrapolation of energy demand values for Australian Aquaculture companies in the FY2018/19 and FY2019/20 (energy demand ratio 14.34 GJ/HOG tonne, Hemer, 2019, p.4) (Author's own).

Company	**Energy Extrapolation [GWh]**		
	FY2018/19	*FY2019-20*	*Annual change*
Tassal	128.09	140.44	10%
Huon	74.96	108.96	45%
Petuna	23.95	29.78	24%
Total	**227.02**	**279.19**	**23%**

Table 22 shows that Tassal holds the largest energy demand and it will likely reach up to 140 GWh or 505,600 GJ by the end of the year 2020. Further extrapolation for Huon suggests an energy demand of 109 GWh or 392,256 GJ. For Petuna, energy demand is estimated to reach 30 GWh or 107 220 GJ by the end of the year 2020.

The percentage growth in energy demand from FY2019 to FY2020 for Tassal is 10%. The percentage growth represented in energy demand from FY2018/19 to FY2020 for Huon and

Petuna amounts to 45% and 24%, respectively; the associated energy calculated from production aligns closely to the scale of each aquaculture company.

The other energy calculations reference Troell el al (2004), which is relevant because the ratios are based on energy input for salmon intensive cage farming ratios per operation (Annex 10, Table J). This aligns with the focus of this research where the production of each of the three aquaculture companies considers only salmon species, for simplicity and time sake. The energy demand ratio (Annex 10, Table J) is converted to GJ/tonne with the assumption that the kilogram (kg) weight is the head on gutted (HOG) weight, in order to match the production volume data reported by the Government for salmon farming in the state of Tasmania. The HOG weight is the same as the Whole Fish Equivalent with the difference being gutted loss (Marine Harvest, 2015).

Table 23: Extrapolated energy input for salmon (intensive cage) farming in Gigajoules for the year 2019-20 of Australian Aquaculture companies (Author's own) (adapted from Troell et al. 2004).

FY2020	Salmon production energy input [GJ]			
Company	**Equipment**	**Feed**	**Electricity, fuel**	**Total**
Tassal	209,430.14	2,757,496.90	418,860.29	**3,385,787.33**
Huon	162,483.00	2,139,359.47	324,966.00	**2,626,808.46**
Petuna	44,413.14	584,773.04	88,826.28	**718,012.47**

Table 23 suggests a total energy input for each company that is much larger than the total energy calculated based on the energy ratio referenced by Hemer (2019). This is because the energy intensity inputs are used rather than energy ratios specific to fish weight. The article by Troell et al. (2004) provides two energy ratios based on the percentage of protein (20%) of product wet weight and percentage of edible (60%) product (p.8). Without knowing the variance from volume production HOG tonne to the weight of product, the energy ratios were not used for calculation. Rather the energy intensities are found to understand which operational component in an intensive salmon farming system are most energy demanding and may be a source for incorporating ORE.

Table 24: Production energy input for salmon farming calculated in Gigawatt hours in FY2019 and FY2020 for Australian Aquaculture companies (Author's own) (adapted from Troell et al., 2004).

Company	**Total Energy [GWh]** *FY2019*	**Total Energy [GWh]** *FY2020*	*Annual change*
Tassal	857.78	940.5	10%
Huon	501.97	729.67	45%
Petuna	160.39	199.45	24%

In table 24, the energy input ratios published by Troell et al. (2004) and production volume published by the Tasmanian Salmon Farming Government database were used for calculating the energy input for each of the three companies investigated.

Table 25: Extrapolated energy input percentage share per operation category for Australian Aquaculture companies (Author's own).

Energy Input share (%)	
Equipment	6.2%
Feed	81.4%
Electricity, fuel	12.4%
Total	100.0%

Table 25 shows that feed (81.4%) makes up the largest of the total energy input share followed by electricity, fuel (12.4%). Electricity and fuel ranks as the second largest input of operations which aligns with the comment shared with the Pitt&Sherry consultant, where the major energy operation is the electric water pumping (Energy & Sustainability Engineer, personal communication, 25 March 2020).

A closer look is taken to Tassal thanks to available data recorded over several years, from 2016 to 2018. The energy ratios and carbon emission values for Tassal are used as a baseline to extrapolate information for the remaining two aquaculture companies, Huon and Petuna.

The calculated energy demand from production at Tassal in 2018 amounts to 442 862 GJ or 123.02 GWh with an energy intensity of 14.34 GJ/HOG tonne (Hemer, 2019, p.4) (Equation 2).

Equation 2: energy usage calculation based on production and energy demand at Tassal (Author's own).

$$Energy\ usage_{total}\ (GJ) = \ production\ (HOG\ tonne) * \ energy\ demand\ (\frac{GJ}{HOG\ tonne})$$

$$442{,}682.22\ GJ = \ 30883\ (HOG\ tonne) * 14.34\ (\frac{GJ}{HOG\ tonne})$$

The production volume of 30 883 HOG tonne is retrieved from Hemer's presentation on the Blue Economy presented at the Ocean Energy Market Development Summit hosted by AOEG in December 2019 (p.4).

The diesel demand amounts to 200, 739.5 GJ, 55.8 GWh (Equation 3) or 45% of total energy demand because the diesel demand ratio is 6.5 GJ/HOG tonne (Hemer, 2019, p.4).

Equation 3: Diesel usage calculation as percentage of energy demand at Tassal (Author's own)

$$Diesel\ Demand\ (GJ) = \ 30883\ (HOG\ tonne) * 6.5\ (\frac{GJ}{HOG\ tonne})$$

or

$$Diesel\ Demand\ (GJ) = \ 0.45 * Energy\ usage_{total}\ (GJ)$$

$$200{,}739.5 = \ 0.45 * \ [\ 30883\ (HOG\ tonne) * 14.34\ \left(\frac{GJ}{HOG\ tonne}\right)\ ]$$

The calculations from equation 1 and 2 is in close alignment with Tassal Groups (2018) published numerical values where diesel consumption stood at 200 000 GJ in FY2017 (table 26).

Table 26: Calculated energy consumption percentage at Tassal from quantitative data recorded in FY17 (Reference data 2018, p.27) (Author's own).

FY2017 **Energy Source**	% Energy consumption of total energy use
Diesel	45%
Petrol	11%
LPG	8%
Total non-renewable	(285,000 GJ)
Electricity	36%
Total energy use (incl. non-renewable)	(443,000 GJ)

Table 26 illustrates that at Tassal the highest contribution to the energy demand is from total non-renewable energy sources (70%). Diesel contributes to a large amount of energy demand (200,000 GJ) when evaluated against total energy use, followed by electricity (158 000 GJ).

Table 27: Calculated change in energy consumption per annum from 2015 to 2017 at Tassal (Author's own) (adapted from Tasmanian Salmon Farming Data, 2020).

Energy source	**2015-16**	**2016-17**	**2015-17**
Diesel	-28%	199%	115%
Petrol	4%	20%	24%
LPG			
Total non-renewable	-19%	165%	115%
Electricity	23%	42%	74%
Total energy use (incl. non-renewable)	-2%	102%	98%

Table 27 shows that in the financial year 2017 there was an overall increase in all non-renewable energy use categories. A notable change was in diesel consumption from 2016 to 2017, which increased by 133,187 GJ. Similarly, a significant growth trend is observed in 2017, where the total non-renewable energy demand increased by 177,573 GJ due to added LPG consumption that was not present in the previous two years. Since 2015 to 2017 and from 2016 to 2017, total energy use increased by 219,766 GJ in the two-year time period and by 223, 915 GJ in the last recorded year; this growth follows the increase in electricity consumption of 74% and 42%, respectively. The positive change in energy consumption suggests that there was an increased activity at Tassal which is confirmed with the growing yearly production volume (Table 21).

Further extrapolation of energy demand and production volume shows that in 2018, the Tasmanian Salmonids Growers Association (TSGA) produced around 63 000 HOG tonne, had an energy demand of 253 GWh, of which 115 GWh was for diesel (Hemer, 2019, p.4). In 2018-2019, the total aquaculture energy demand 200GWh referenced by Hemer (2019) is similar to the calculated total energy estimated at 227 GWh for all three aquaculture companies (Table 22). The TSGA has the mission to support sustainable growth and to progress technical development of salmon producing industries (2020). The website page presents three members of the TSGA: Tassal, Petuna and Huon.

Emissions
Based on emission factors provided by the Department of Environment and Energy (2017) in Australia carbon emission are estimated for 2019 and 2020 in Aquaculture (Table 28). The emission values are used as a basis to calculate emission abatement potential for the sector.

Table 28: Carbon emissions of electricity from current fossil fuel energy system for Australian companies in 2019 and 2020 (Author's own).

Company	Financial Year	Carbon Emissions from Electricity consumption	
		Lower limit [Mt CO2]	Upper limit [Mt CO2]
Tassal	2019	2.37	3.85
	2020	2.60	4.23
Huon	2019	1.39	2.25
	2020	2.02	3.28
Petuna	2019	0.44	0.72
	2020	0.55	0.90

Table 28 shows an increase in emissions from 2019 to 2020 correlating with increased annual production volumes for each of the companies.

Tassal reports to the NGER Act 2007 annually. There is no available information for Petuna regarding emissions accounting or reporting. The last question asked during the interview relates to the carbon price and the interviewee confirms that there is no specific regulation on emissions (Annex 7). The interviewee at Huon shares that the GHG per kilogram (kg) of salmon is lower compared to other protein producing industries (e.g. poultry, beef, lamb), a factor that contributes to the sustainability profile of aquaculture companies. Actually, the salmon industry is one of the most regulated industry in the state (Tasmania) and companies need to evaluate and report their carbon emissions to the national and federal government (Environmental Compliance and development manager, personal communication, May 5, 2020). Emissions in table 28 are overall higher than the total emissions associated with TSGA production in 2018 is estimated at 66 kilotons of carbon dioxide equivalent (kt CO_{2e}) (Hemer, 2019, p.4). The variance in emission may be explained by a different emission factor used by the TSGA, or resulting from a notable increase in activity.

5.1.2 O&G

The following section seeks to answer sub-question 1 respective to the O&G sector of the BE, with quantitative and qualitative data. The information combines literature sources and responses pertaining to the following interview question:

i) How important are energy costs and needs in O&G industries?

Energy

The supply chain includes the production, transformation and transportation where electricity accounts for approximately 10% of the processes, with the oil refining (i.e. transformation) accounting for about half of all the energy consumes, so it is the most intensive compared to the extraction (i.e. production) and transmission via pipelines (i.e. transportation) (IPIECA, 2007). In general, companies are working toward improving energy efficiency in the extracting and processing phases of operations (Edwards, 2004). Limited data is available on energy usage over several years for O&G industries. It is difficult to draw a coherent trend between the O&G industries because the types of energy output recorded are based off different categories (e.g. total energy use, net consumption, energy production) and years. Due to company information privacy on sustainability targets within the O&G sector, no specific energy use was shared during interview conversations. Literature sourced data is used to illustrate energy use for the five case study companies (Table 29).

Table 29: Energy usage values for five Australian O&G case studied industries (Arrow, 2015a, p.81; XXX, 2018, p.36; Conoco, 2018; Woodside Sustainability Hub, 2020).

Company	Energy	Year	Notes
Arrow Energy	21,000 TJ	2012	Energy production
A Top 5 ASX Energy	679.39 TJ 679.39 TJ	2018	Net energy consumption Gross energy consumption
Conoco Phillips	64,358 TJ 0	2018	Total energy use – combustion energy Imported electricity
Woodside Energy	140,433 TJ 43 TJ	2018	Total fuel consumption – resource use Grid electricity consumption
	129,412 TJ 37TJ 4.5 TJ/kt	2019	Total fuel consumption – resource use Grid electricity consumption Fuel intensity
Carnarvon Petroleum	N/A	N/A	N/A

In table 29, Carnarvon has not reported public information on resource use and/or GHG emissions because of the small size of the company. In the year 2018, the above table shows that Woodside has the largest resource use, with about 140 000 TJ, followed by Conoco Phillips reaching close to 64 500 TJ, and then the anonymous company with close to 680 TJ. Looking at the company size, specifically number of employees, helps to relatively compare the energy use per company (Annex 11, Table P). While Conoco Phillips has a much higher number of employees than Woodside, the energy use presented for Conoco considers the activity in Australia which is smaller compared to the company's main activity being in the U.S. and other locations (e.g. EU, Canada, Indonesia) and that of Woodside which is a leading Australian company (Conoco, 2018). It is important to note that the value for Arrow energy dates back to 2012 and is actually a measure of energy production so is difficult to compare with the other O&G companies being investigated.

The energy data information presented at Woodside shows there is an overall reduction in resource use and intensity; from 2018 to 2019, there was a 78% reduction in resource use total fuel consumption, a 16% decrease in grid electricity consumption, and a 2% reduction in fuel intensity of fuel consumption - specifically from 4.6 to 4.5 TJ/kt (Woodside, 2020). To simplify data synthesis the fuel consumption and fuel intensity associated with Woodside's equity of operations are not included for this results analysis (Annex 8, Section 2, Table H). Arrow Energy, Top 5 ASX company and Conoco Phillips report a unique value of energy use for a year, where Conoco has the largest energy use, all sourced from combustion and none from imported electricity (2018). The energy use value at Conoco is converted from trillion British Thermal Units (BTUs).

Emissions

Emission from the literature are shown in Table 30. Then for companies that have detailed data published, the results are displayed to serve as an example and overview for the O&G. Lastly, emissions for the remaining sectors are calculated from the energy use calculated in SQ1 and based on the emission factors mentioned above.

Table 30: GHG Emissions values for five Australian O&G case studied industries (Arrow, 2015a, p.81; XXX, 2018, p.36; Conoco, 2018; Woodside Sustainability Hub, 2020).

Company	Emissions [ktCO2e]	Year	Notes
Arrow Energy	1.076	2012	Direct scope 1 & 2
	47.1	2012	Indirect scope 1 & 2
A Top 5 ASX Energy	43.8	FY2018	Scope 1
	0.37	FY2018	Scope 2
	44.17	FY2018	Total (scope 1 & 2)
Conoco Phillips	4200		Total GHG
	108.94	2018	Calculated from total operated production value
Woodside Energy	9,767	2018	Scope 1
	8	2018	Scope 2
	8,840	2019	Scope 1
	7	2019	Scope 2
	74,017	2019	Scope 3
Carnarvon Petroleum	N/A	N/A	N/A

Table 31 illustrates scope 1 and 2 emissions examples within an O&G company.

Table 31: Arrow Energy definition examples of scope 1 and 2 emissions as follows (2014).

Scope 1 emissions	**Scope 2 emissions**
• Emissions from fuel gas due to combustion of CSG for power generation. • Fugitive emissions from venting and flaring. • Emissions from combustion of liquid fuels (petrol and diesel) used in transport vehicles and diesel	• Emissions from grid-purchased electricity (NEM) for facility use. • Indirect emissions at power stations.

Company examples

Conoco Phillips and Woodside are used as specific examples for sustainability strategy and actions to move away from emissions related production.

ConocoPhillips has been working on a climate action plan since 2008, taking emission reduction measures. As of 2018, the total gross operated GHG emissions were about 20.3 million tonnes $CO_{2\text{-}e}$, a decrease of about 1.45% (0.3 million tonnes) from 2017 (2020b).

The primary mitigation action plan sets the following steps:

1. Understand EE baseline levels to help achieve reductions in GHG intensity *(create cost of supply metric incl. cost of carbon where legislation exists)*

2. Complete an energy optimization study *(MACC data to identify viable projects)*
3. Progress toward pipeline decommissioning *(switch to temporary generators)*
4. Purchase offset requirements *(for compliance with emissions regulations)*

The report outlines a number of scenario planning and mitigation objectives (Table 32).

Table 32: Climate change management strategy per type of technology (tech) development (dev) and/or regulatory carbon (C) scenario (ConocoPhillips, 2020).

Type	Description
Scenario 1:	Rapid tech dev with low C price introduced by government to accelerate tech progress and dev. Fast transformation and breakthrough in tech (e.g. power storage, EEI) allows significant GHG emission reduction.
Scenario 2:	Global legislation to limit GHG emissions by C pricing mechanisms and tech innovations. Could lead to rapid development of lower-cost alternative energy and Carbon Capture and Storage (CCS). With higher C price, may be EEI, renewable power generation & coal-to gas fuel switching; gas demand is offset by RE increase.
Scenario 3:	Tech adoption is slower because emphasis is on national trade and energy security. In this case, there could be an expansion of EE and in areas with abundant of domestic supply of fossil fuel, a reliance on coal use.
Scenario 4:	Introducing command and control measures to push for the development of higher-cost alternative technologies. Natural gas demand remains higher for a longer period because of the urgency to reduce coal usage.

The company has researched climate related risks and organised a set of actions to tackle each on based on the related time period (i.e. short-term. Medium-term, and long-term) (Table 32).

Table 33: Climate change adaptation target and performance at Conoco Phillips (2020).

Year	Target Description	Performance
2030	Reduce GHG emissions intensity from 5% to 15% from a January 1st, 2017 baseline	Reduction of almost 7 Mt $CO_{2\text{-}e}$ annually since 2009.
2018	Voluntary emissions reduction program; high target 37.0 kg/BOE and low target 33.0 kg/BOE	Gross operated global BAU GHG emissions were reduced by about 26%

The 2030 GHG reduction target could serve as an example and baseline for the other O&G companies. If companies work together to be the first movers in tackling emission abatement, benefits could be shared between all participants rather than in competition with one another. Being a first mover would make for a more rapid transition and avoid an imposed, potentially drastic government policy.

Woodside

Woodside Energy is used as a specific example because of available literature data that can help to understand trends in emissions volume for large scale O&G activity held mostly offshore (Annex 11, Table Q, R). The results suggest that the largest source of GHG emissions at Woodside is from fuel combustion (73%) followed by venting (20%), then flare (7%); Accordingly, from 2018 to 2019, there is a decrease in overall 9% decrease in emissions for scope 1 and 2 source operations with the largest decrease in venting (14%) followed by flare (13%) and fuel combustion (8%) (Annex 11, Table U, Figure H).

Summary

Overall the O&G sector has a high energy use and demand, in thousand Terajoules per year. The drilling rig platform system requires three main forms of energy for production: fuel gas, diesel and electricity all of which could be, at least partially, sourced from a tidal turbine or WEC (Edwards, 2004). The Atteris company representative confirms that with a 24 hour, 7 days a week running of operations the O&G sector is high energy intensity (Asset Lifecycle Manager, personal communication, 25 March 2020). The NERA company representative shares that the main power is for facility, pump and electrical processes as well as the gas transport from offshore to shore (General manager innovation and strategy, personal communication, 19 March 2020).

The majority of companies report under the NGER Act. All companies have annual published sustainability report except Carnarvon, which has an annual report and no sustainability directives. Arrow Energy writes in the 2013 sustainability report that natural gas helps contribute to reduced GHG emissions when compared to the combustion of other fossil fuels. Similarly, the company has written a five-year assessment plan to cover energy use across operations. The Top 5 ASX company seeks to integrate low emissions technologies in operations where it is economically viable. The company is undertaking emissions reduction projects, such as incorporating solar power into production and processing facilities as well as assessing the potential for carbon capture and storage (XXX, 2018).

The consultant at Pitt&Sherry suggests that most projects are motivated by corporate social responsibility (CSR) because there is no carbon cost scheme in Australia.
Carnarvon is also working to lower emissions in a cost-effective manner where the strategy is based on cost factor of RE in order to remain competitive on the global market (2019). Conoco Phillips is aware that climate-related risks may have an impact on the business, so are seeking low carbon alternatives and is engage in emissions reduction measures. Specifically, Conoco targets to reduce emission intensity from 5% to 15% by 2030, and reach carbon neutrality by 2050 (2020a). Since 2008, Conoco has engaged in emission reduction measures and finds that reduction projects prove to pay for themselves. Woodside targets 4% energy efficiency improvement (EEI) against baseline in 2019, 5% EEI by 2020 and to reduce GHG emissions annually by 7,000 tonnes (Annex 11, Figure I). Similar to Arrow Energy's statement for carbon emissions mitigation, Woodside writes that natural gas is a solution for supplying energy because gas displaces higher emission fuels. In terms of carbon neutrality, Woodside has the same ambition as Conoco by 2050.

5.1.3 Ports

The following section seeks to answer sub-question 1 respective to the Ports sector of the BE, with quantitative and qualitative data. The information combines online literature sources and responses pertaining to the following interview questions:

ii) How important are energy costs and needs in your Port?

Energy

Port of Brisbane

Table 33: Energy use per type at Port of Brisbane in the financial year 2018 and 2019 (p.33).

Energy Type	FY18	FY19	Change
	Energy consumption (GJ)		
Diesel	136,545	131,683	-3.56%
Unleaded	221	215	-2.71%
Solar production	677	794	17.28%
Electricity	12,491	11,539	-7.62%
Total	**149,934**	**144,231**	**-3.80%**

Table 33 shows a decreasing trend decrease in both diesel (-3.5%) and electricity (-7.6%) energy consumption, that is compensated with an increase in solar (17.3%) renewable energy source at the Port of Brisbane over the past year, 2018-2019.

Diesel is predominant in the port's energy mix (91%) compared with electricity (8%) at the Port of Brisbane in 2018 and 2019; Solar use is a negligible component with less than 1% share in the energy mix in the same time period (Annex 13, Figure J).

The interviewee shares that fuel energy pricing is the largest impact on operations. Then, the main driver for green energy is emissions reduction, with most efforts done internally through efficiency initiatives (Envr. Manager, personal communication, April 4, 2020).

Port of Broome

There is no quantitative data found for PB. Responses from the interview suggests that there is energy tracking for equipment that run on diesel but given the limited energy use management there is a lack of records available.

The interviewee shares that there is no plan for reducing energy usage at this stage, though some strategies have been identified to reduce energy use. Another fact to take into account is that because of the port's small size PB is not required to report carbon emissions data (HSE manager, personal communication, May 15, 2020).

Port of Esperance

The Port of Esperance organizes its electricity data into six different categories per source type (Table 34).

Table 34: Summed electricity use (purchased) for the FY2019 at PE (adapted from data provided by Envr. Manager, personal communication, May 12, 2020).

July 2018 - June 2019	Total electricity	CBH usage (CBH Main + Office)	McKenzies Tugs	Summit sub-zero usage	Customs usage	Electricity usage*
Total (kWh)	12,614,022	5,379,983	110,620	70,362	23,082	7,029,975
Total Energy (GJ)	**45,410**	**19,368**	**398**	**253**	**83**	**25,308**

*The CBH group is Australia's largest co-operative and grain industry (2020).
*The electricity usage in the last column does not include the lease holders.

Table 34 suggests that electricity usage is 55.7% of total electricity. Lease holders make up a significant component (44.3%) of electricity demand at the port of Esperance, which makes sense give the large size of vessels and clients that dock and come through.

Table 35: Calculated change in electricity use for the FY2019 at PE (Author's own).

Source Type	**Total Energy** (GJ)	**Annual Change** (%)
Total electricity	45410.48	24%
CBH usage (CBH Main + Office)	19367.94	-71%
McKenzies Tugs	398.23	26%
Summit sub-zero usage	253.30	-20%
Custom usage	83.10	-11%
Electricity usage (not including lease holders)	25307.91	194%

The calculated change in electricity is based on the difference of the electricity (kWh) recorded in July 2018 and the value recorded in June 2019. Table 35 displays a notable growth (194%) in total electricity use (excluding lease holders) in the year 2018-2019. The largest decrease (71%) in electricity use in the year 2018-2019 is observed in the CBH usage. Limited information was provided during the interview to explain the surge of electricity use at the port for the time period between 2018 and 2019. The decrease in energy use associated with CBH and the two other customers listed in the table may be due to a a slowdown of activities or an improved management, efficiency of resource use.

The interviewee shares that there is collaboration between the environmental, electrical and engineering teams to look at alternative energy sources. Energy savings are being included in the port's installations, such as smarter technologies on the conveyor belt (carrying bulk minerals) (Envr. manager & envr. advisory, personal communication, May 12, 2020).

Port of Gladstone

Table 36: Net energy consumed and calculated annual change of energy at the PoG for the years 2016-2019 (CER, 2020, 2019, 2018).

Year	**Total Net Energy consumed** (GJ)	**Annual change** (%)
2018-19	916,467	7%
2017-18	854,490	-9%
2016-17	938,703	-

Table 36 shows that there has been a relatively stable volume of energy demand consumed each year with the lowest consumption occurring in 2017-2018. From 2017-2018 to 2018-2019 there was 7% increase in total net energy consumed, which contrasts with the year prior that shows a decrease by approximately the same magnitude (9%). From the FY2017 to FY2019 there was a small reduction in net energy consumed, specifically by 2%. As the quantitative information is retrieved online, it is difficult to understand the factors that impact the energy consumption at the Port of Gladstone. The flux of activities and associated energy use was not discussed in the interview.

The interviewee shares that there are no current mandated requirements or set targets, rather PoG uses SDGs as guidance for sustainability management. PoG is investigating methods to diversify their present energy mix and needs a prospect approach because the port is locked into long-term energy contracts. Furthermore, the potential investment in renewables is bounded by Queensland policy, which will direct the port's decision making for adopting RE (Sust. specialist, personal communication, January 30, 2020).

Port of Townsville

The port of Townsville has records of energy consumption for both diesel and unleaded fuel. In the scope of this research the diesel consumption is highlighted because most sectors also have diesel numbers, thereby making it possible to draw a comparison between the case study industries. PT categorizes energy consumption based on vehicles, floating plant and land-based plant (Table 37 - 42). Vehicle transport includes three types of transport modes: cars, utes and trucks, which are in use every day and rely solely on diesel. The year 2016 is the baseline year.

The data displayed in tables 37-45 is an integration and analysis from original data provided by the manager strategy & sustainability, via personal communication on April 2, 2020

Table 37: Energy diesel consumption for vehicles at PT from 2016 to 2019. The category of vehicles is composed of data from cars&utes and trucks.

Vehicles		**Diesel (GJ)**
Baseline Year	2016	1595.80
Measurement Year	2017	1813.16
Measurement Year	2018	1702.30
Measurement Year	2019	2541.16

Table 38: Calculated change in energy diesel consumption for vehicles at PT from 2016 to 2019. The baseline reference is 2016 (Author's own).

Diesel consumption		
Vehicles	**Change per year**	**Baseline comparison**
2016/17	14%	14%
2017/18	-6%	7%
2018/19	49%	59%

Table 39: Energy diesel consumption for the floating plant at PT from 2016 to 2019.

Floating plant		**Diesel (GJ)**
Baseline Year	2016	9230.23
Measurement Year	2017	10495.23
Measurement Year	2018	7574.79
Measurement Year	2019	8033.71

Table 40: Calculated change in energy diesel consumption for the floating plant at PT from 2016 to 2019. The baseline reference is 2016 (Author's own).

Diesel consumption		
Floating plant	**Annual change**	**Baseline comparison**
2016/17	14%	14%
2017/18	-28%	-18%
2018/19	6%	-13%

Table 41: Energy diesel consumption for the land-based plant at PT from 2016 to 2019.

Land based plant		**Diesel (GJ)**
Baseline Year	2016	265.52
Measurement Year	2017	353.83
Measurement Year	2018	258.72
Measurement Year	2019	583.96

Table 42: Calculated change in energy diesel consumption for the floating plant at PT from 2016 to 2019. The baseline reference is 2016 (Author's own).

Diesel consumption		
Land plant	**Annual Change**	**Baseline comparison**
2016/17	33%	33%
2017/18	-27%	-3%
2018/19	126%	120%

The tables 37-42 indicate that at PT, the floating plant is the source of highest energy consumption, followed by vehicles, and then the land based plant. The floating plant being further located from the shore and the grid inevitably requires more complex infrastructure as well as a higher amount of energy sourcing.

There is a notable increase in diesel consumption from 2018-2019 and since 2016 at the land based plant as well as for vehicles. Conversely, the floating plant suggests a lowering trend of diesel consumption since the baseline year.

PT records information on the electricity purchased from different providers. The data is included in this investigation because it can represent the energy consumption and the trend in the past four years (i.e. 2016-2019). Electricity consumption was provided in MWh, but the unit of GJ is chosen to maintain consistency with data from other industrial sectors (i.e. O&G, Ports).
The tables 43- 45 show electricity consumption at the Port of Townsville expressed in GJ from 2016 to 2019, with the year 2016 set as the baseline measurement.

The data illustrated in tables 43- 45 was provided by the manager strategy & sustainability via personal communication on April 2, 2020.

Table 43: Electricity usage from 2016 to 2019 provided by four electricity suppliers at PT.

Electricity (GJ)				
	2016	**2017**	**2018**	**2019**
Provider A	63.21	59.30	58.57	58.26
Provider B	159.77	123.31	126.31	173.17
Provider C	114.09	71.95	59.36	52.92
Provider D	1887.06	1839.69	1847.06	1795.10
Total				**2079.5**

Table 44: Calculated change in electricity from 2016 to 2019 provided by four electricity suppliers at PT (Author's own).

Electricity change per year			
	2016/17	**2017/18**	**2018/19**
Provider A	-6%	-1%	-1%
Provider B	-23%	2%	37%
Provider C	-37%	-17%	-11%
Provider D	-3%	0%	-3%

Table 45: Calculated change in electricity from 2016 to 2019 in comparison to baseline reference year 2016 at PT (Author's own).

Electricity baseline (2016) comparison			
	2016/17	**2017/18**	**2018/19**
Provider A	-6%	-7%	-8%
Provider B	-23%	-21%	8%
Provider C	-37%	-48%	-54%
Provider D	-3%	-2%	-5%

Table 43 suggests that Provider D is the largest amount of electricity provided throughout all years but with a decreasing trend since 2016. There is a notable growing decrease each year and since 2016 in the electricity sourced by provider C (Table 44). Overall, all four electricity providers have provided a reduced volume of electricity since 2016 (Table 45). This suggests that the port is consuming less energy or there has been an increase in energy efficiency or improved resource management, planning. Provider B is the only source which had a positive increase in the electricity provided since 2016 when evaluating the latest data in 2018-19.

The following paragraphs discusses trends in energy consumption of all five ports observed.

Diesel

There is a dominating diesel energy consumption (92%) in the year 2018-2019 at Brisbane Port. At PB, the absolute diesel energy consumption in the FY2019 amounts to 131 683 GJ. At PT, the diesel consumption is significantly higher than unleaded gas use for all source categories, especially the floating plant with 60-80 times more per year than vehicles and land based plant. For cars&utes the diesel and unleaded fuel use is about the same, but slightly more for diesel, with one to two times more per year. There is no evidence of diesel energy record at PB, PoG and PE, though it is highly likely that it is a source of energy to carry out operations.

Electricity

The absolute electricity consumption at PB in FY2019 amounts to 11,539 GJ or composes about 8% of the energy mix. PE has a much larger reliance on electricity with a total consumption of

45,410 GJ in the same financial year. The electricity associated with PE's lease holders or various clients makes up 44.3% of total electricity use, an estimated 20,117 GJ. The PoG has more than six times the total net energy consumption of Brisbane, with 916,467 GJ in 2018-2019. No electricity consumption data is available for PoG so no relative comparison is made with the other investigated ports. PT provides the most detail in diesel energy use per source, notably for vehicles the port's floating plant and land-based plant. Unfortunately, no additional material or details are known about the two different plants at PT, but when analysing the diesel fuel use of each plant in 2019, the floating consumes almost 14 times more than the land based plant. The floating plant remains the largest diesel consumption source when evaluated against vehicles, whose diesel use amounts almost a third of the floating plants' 8,033.71 GJ of diesel in 2019. However, the land based plant experienced the largest increase (126%) and (120%) in diesel demand in 2019 and since 2016, respectively. The aforementioned growth may suggest a higher flux of activity which is also seen with vehicles which increased diesel usage between 50-60% in both 2019 and since 2016. The total aggregated electricity use at PT in 2019 amounts to 2079.45 GJ. Compared with the PI and PE, PT's electricity usage is much smaller amounting to 18% and 5% of each port's total electricity recorded in 2019, respectively.

5.1.4 Emissions

The subject of emissions is discussed first supported by information from the literature and interview conversations. Then emissions are calculated from the energy use data analysed above and based on an upper limit, pessimistic, and lower limit, conservative, range with the carbon factor of 51.4 kg CO_2/ kWh and 66.9 kg CO_2/ kWh, respectively (Dept. Envr., 2017) (Table 46).

PI targets 24% emission reduction by 2024-2025 and launched a strategy to achieve net zero emissions by 2030 (PBPL, 2019, p.7). For now, PI has no record of scope 3 emissions. Port Broome tracks energy for equipment that runs on diesel, otherwise there is limited energy use management. PB engages mostly in environmental management but is seeking to integrate sustainability, for example by improving performance of operations (KPA, 2018, p.11). PoG affirms that 98% of energy use is to run their coal power plant terminal (Sust. specialist, personal communication, January 30, 2020). PoG monitors the handling and use of hydrocarbons and electricity as a way to improve energy and GHG performance and work toward an overall reduction goal (GPCL, 2020).

Table 46: Carbon emissions of electricity from current fossil fuel energy system for Australian Ports in 2019 and 2020 (Author's own).

Port	**Emissions from electricity [kt CO2]**	
2019	Lower limit	Upper limit
Brisbane	164.8	214.4
Esperance	648.4	843.9
Gladstone	1046.9	1362.5
Townsville	29.7	38.6

Table 46 shows that PoG has the largest volume of emissions, above 1 Mt Co_2. PE is the second largest emitter which aligns with the significant reliance on electricity for its clients. PI has about a quarter the amount of emissions compared with Esperance and close to 16% of the emissions compared with PoG. PI's emission performance aligns well with their investment in solar energy to source electricity and reduction in diesel and electricity use from 2018 to 2019. PT, the smallest port of all ports investigated has the lowest amount of emissions with less that 40 kt CO_2 estimated in 2019. PT's limited emissions aligns with the observed decrease in all energy sources reported at their port. Additionally, the length of detailed energy record shows an advance energy system management and oversight at PT.

Current sustainability practices on operations include, efficient lighting, fuel efficiency specifications for the vehicle fleets, scheduling efficiency and monitoring resource consumption. PT has a set baseline for direct energy consumption. PT aims to be carbon positive and 100% renewable energy by 2050 with a business case strategy to integrate RE (Manager strategy & sust., personal communication, April 2, 2020). The largest emissions at PT is from daily activities and the port is working to include customer energy use in scope emissions record.

For the port sector, the main energy usage is for operations [equipment, transport], facilities [buildings] and direct consumption [lighting]. The majority[6] of ports identify no issues to meet their required energy demand. Possible constraints on energy supply will depend on factors of fuel pricing, main supplier decision and time frame of locked-in electricity contracts.

Overall, there are efforts for sustainability but it is not necessarily a priority. Some measures include lighting efficiency, emission reduction and carbon positivity goals. Ports are taking into account GHG performance and following SDGs for guidance (Annex 6).

5.2 Technical potential (SQ2)

First, interviews held with technology developers are presented to then calculate the technical potential for ORE within the three industrial sectors studied. Then each industrial sector is analysed with results from the literature and from interview conversations. A concise summary of responses to the interview questions can be found in Annex 6. With the combined information, an estimate is made for carbon emission abatement that could be displaced with ORE power generation uptake over the fossil fuel based electricity use of each company, per sector.

Emissions per sector are calculated based on two emission factors, to create a lower limit and upper limit, 51.4 kt CO_2 and 66.9 kt CO_2 respectively for carbon emission abatement potential (Dept. Envr., 2017). Emission abatement is based on the displacement of fossil fuel based electricity input with ORE technology, estimated as a null emission output since it is a renewable source. Then, the calculated ORE power generation potential (in GWh) is used to calculate the emission abatement in kiloton carbon dioxide (kt CO_2) (equation 4).

Equation 4: Emission abatement potential per sector for electricity use

[6] The majority is at least three out of the five ports under investigation

$$CO_2\ abated\ [kt] = ORE\ potential\ [GWh] *\ emission\ factor\ \left[\frac{kgCO_2}{kWh}\right] * \frac{10^6 kWh}{Gwh} * \frac{1\ kt}{10^6 kg}$$

1) Technology developers

The following descriptive paragraphs inform the potential for ORE from the perspective of tidal and wave technology developers. The information combines online sources and responses pertaining to the following three interview questions:

i) “What is the projected capacity you are hoping to provide?”
ii) “How and when do you expect commercialization of your product?”
iii) “What is your growth strategy?”

Bombora
Bombora has the current project to build a first prototype with a capacity of 1.5MW, to install several single units, and a long-term goal to scale up to 20 MW by 2030 and then provide hundreds of MW (Annex 12, Table W). The company is looking to collocate wave offshore with floating wind to help power offshore rigs. A strategy is to place the turbine on concrete rather than steel to cost less and obtain a better rate of energy. The interviewee estimates that commercialization will take place by 2030, where the company hopes to half the cost in the near-future and afterward by increments of 20%.

(Commercial Manager, personal communication, May 1, 2020).

B0mbora has three future projects planned (Annex 12, Table W to progress into the commerciality of the low-impact WEC in i. Orkney Island (UK), ii. Peniche (Portugal) and iii. Albany (Australia). The project objectives, respectively, are i. the commercial deployment for pre-consented and grid connected sites, ii. a 60 MW wave farm and iii. a small- scale array of 1.5MW mWave converters to serve as a mid-term pipeline input for future commercial deployment.

(Bombora, 2019d,e,f).

Carnegie
The CETO technology is based on a modular array design to make it easily scalable (Carnegie, 2020). The company has invested and accumulated over “10’000 hours of ‘in-ocean operational testing” for more than 10 years though a multitude of projects (Carnegie, 2020, p.1) (Annex 12, Table X). Carnegie is collaborating with the BECRC and has received funding from ARENA to progress on the device electricity conversion and cost reduction (2019). The written business strategy for commercialisation focuses on the following:

- Pursue partnership with commercial partners to reach competitive cost level and market opportunities (next 24 months).
- Engage with utility scale partners to build and use CETO units on commercial scale (next 24-36 months).

(Carnegie, 2019a).

MAKO

MAKO owns engineering facilities and machining equipment which allows them to directly design fabricate, test and improve the structural components with high time efficacy (MAKO, 2019b). The MAKO design is versatile and suits a large majority of flow locations in the world with a velocity range between 1.5-2.5 meters per second (m/s) (Annex 12, Table Y, Z). The company is directing efforts toward the Asian market because there is an unlimited opportunity to scale-up on bridges and wharves infrastructure (e.g. multiple MW arrays) (CEO, personal communication, April 22, 2020). Indeed, the technology has been deployed successfully in multiple locations and target sites (Table 47).

Table 47: Deployment site infrastructure and operation of the MAKO turbine (2020c).

Site Infrastructure	Geographical Location
Barge	Sydney, AU Kagoshima, Japan
Bridge	Sentosa, Singapore
Wharf	Port of Gladstone, AU

Sabella

Current contracts are with small scale farms, so project developments are aligning with installation potential of maximum four machines. Sabella has developed and tested their turbine designs in multiple precommercial projects to assess the fundamental features of the technology (Annex 12, Table AA). Sabella is reinforcing the reliability of its technology and exploring ways to significantly decrease the need for maintenance operations. Meanwhile, the company is working on three main targets to secure commercial viability, which are (Sabella, 2020h):

1. Investment cost cut
2. Optimization of the reliability of the device by reducing failure risks
3. Secured availability of the turbine for power generation

The company recognizes that to meet industrial sale, a larger the design size will be needed. In the long-term, (e.g. 2050), future energy models will call for machinery with 20MW capacity (Commercial Development Engineer, personal communication, April 24, 2020).

WaveSwell

In the short term the focus is to pursue project opportunities where the technology can deliver immediate solutions, for example, replacing costly diesel in isolated areas. In the longer term the company aims to upscale wave energy into a complimentary base load power source and large-scale grid connected electricity (2019a).

The company is developing a 200-kW wave energy project on King Island, Tasmania (ARENA, 2020) (Annex 12, Table AB). The project will deliver energy to complement hydro Tasmania's existing high level of wind and solar grid (Sabella, 2019c). Earlier testing showed that the company's innovative features result "in a combined 60% increase in output compared to other OWCs (WSE, 2017a, p.1) Before the tank tests, the company expected to start a commercial phase with a LCOE below 10 cents per kWh, whereas the test results prove to be more cost effective because the device is place in shallower water (i.e. 5.75m deep) (WSE, 2017).

Summary

Technology developer companies are well advanced in the phases of project demonstration and increasing device power output capacity (Annex 12, Tables W- AB). The five technology developer companies interviewed have a current power capacity ranging between 1.5-3.0 MW with long-term objective to deploy multiple unit array farms and then commercial scale devices (Figure 5). All five developers have undergone several prototype trial tests and demonstration projects with target customers (e.g. Department of Defence, microgrid/island communities, ports) in order to determine the design performance, electricity generation potential and multiple renewable energy system integration per type of location (Table W-AB, Annex 12). ORE catapult representatives suggest that there are opportunities in auxiliary markets (Analysis & Insights and Senior Mng. Researcher, personal communication, 18 March 2020). The technology companies investigated in this research share that the main customer area is small-scale niche markets, micro-grid communities, ports and offshore (because of existing infrastructure). An important strategy to achieve commerciality is to de-risk and improve the durability of the technology. Another method to achieve lower costs and ensure economic viability is to shape an integrated multiple renewable energy system that can ensure continuous source of power and builds capacity to displace fossil fuel use.

Limited data is available on the costs incurred per company. The unanimous point raised by companies is the challenge to achieve competitive costs and securing government support. The consultant representing Pitt&Sherry reiterates that there is a need for reliable technology that is less expensive (Asset Lifecycle Manager, personal communication, 25 March 2020). Carnegie suggests that pairing (wave) energy with other renewables helps reduce intermittency and lower the overall risk of the projects since these energies have a proven track record (2019). Similarly, Sabella says that coupling ORE to other electricity sources helps promote a carbon-free energy model and reduce the cost of energy per MWh (2020j). Companies are seeking to collaborate with industries and service providers because it advances the reliability of ORE in different contexts and spreads the knowledge of the technology.

The following figure displays current, near-term and future power capacity of tidal turbines and wave devices based directly on technology developer's expertise as well as the literature. A description of past, current, future projects per company can be found in Annex 12.

Figure 5: Current and future estimated power capacity for tidal and wave technology (Author's own).

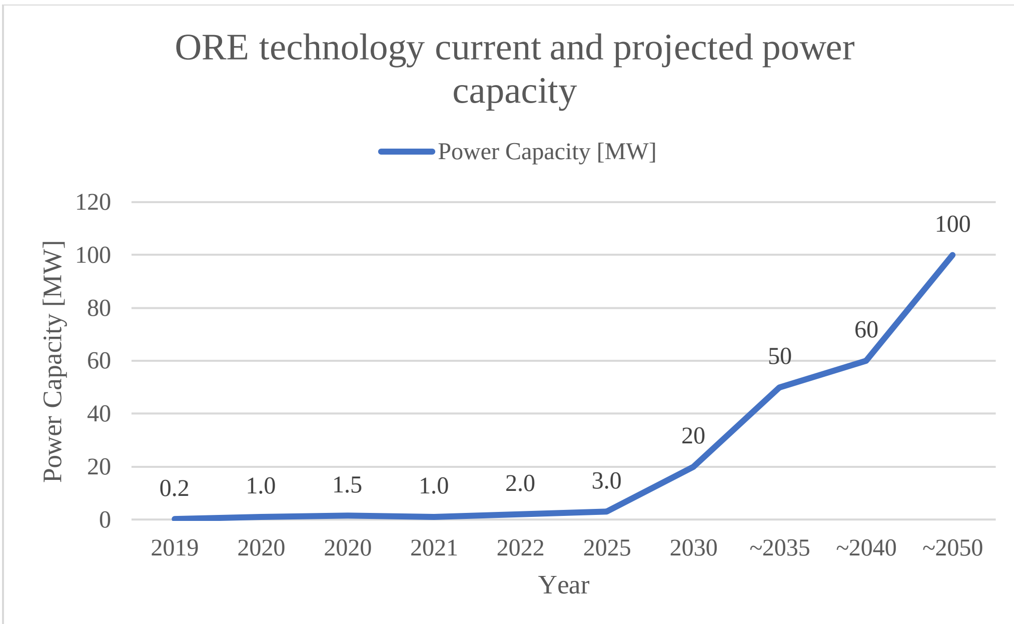


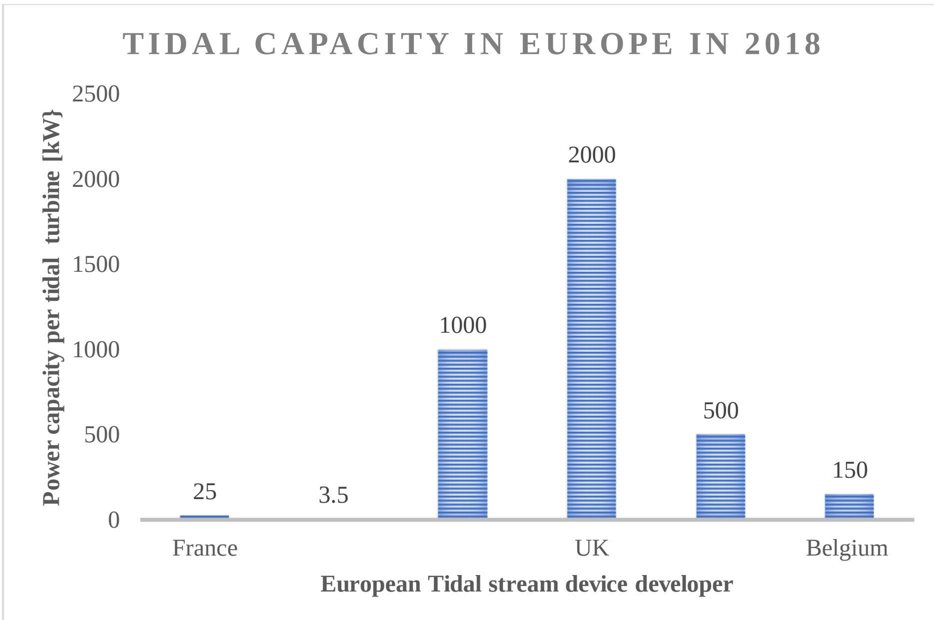
Figure 5 shows that in the next five years, by 2025, the majority of tidal turbines and wave devices will be deployed as single unit arrays reaching up to 3 MW by 2025 compared with the current power output ranging between 1.0-1.5 MW (i.e. in 2020). Opinions are that by 2030 multiple array farms may be deployed to reach up to 20 MW of power capacity. Considering the lack of information on a specific year associated with higher power capacity potential, the years are estimated as 2035, 2040 and 2050. However, based on acquired knowledge from interviews and published sources a suggested estimate is that power capacity could be 50 MW, 60 MW, and up to 100 MW, respectively.

Information is used from tidal and wave capacity developments in Europe to help estimate the power potential of ocean devices that can be installed in Australia (Figure 6-7). The aim is to observe the progress in scaling of power capacity per number of devices and integrate the growth in calculations.

In Europe, the rate of tidal stream capacity installation has accelerated since 2015, where in 2018 there was more than double the capacity in 2017 (OEE, 2018, p.5). Since 2010 there has been almost 30 MW of cumulative tidal stream devices and close to 12 MW of wave energy deployed in

Europe (OEE, 2018, p.6,7). In 2018, in Europe the average WEC capacity is estimated at 60 kW with successful completion of testing projects, thus continuing the development of wave energy. In 2018, the cumulative power produced by tidal stream reaches nearly 35GWh, up from an estimated 15 GWh in 2015. To have additional information on the progress of power output capacity, Figure 6 and figure 7 illustrate recent tidal stream and wave device deployment in Europe.

Figure 6: Tidal stream deployment capacity in Europe in 2018 (adapted from OEE, 2018).



Tidal power output capacity per turbine device per country is shown in Europe in 2018 in Figure 6. The graph suggests that there is a large range in power capacity starting at 3.5 and reaching up to 2 MW of power. Each device power output depends on the project deployment advancements of the device and upscaling. The 1 MW output is from Sabella and the 2 MW output is EMEC. This graph puts into perspective that tidal devices are at 2 MW output in Europe. Then, the projection for Australia of 2 MW by 2022 and 3 MW by 2025, is a conservative estimate if knowledge is shared between countries and if European companies increase contracts in Australia.

Figure 7: Wave deployment capacity in Europe in 2018 (adapted from OEE, 2018).

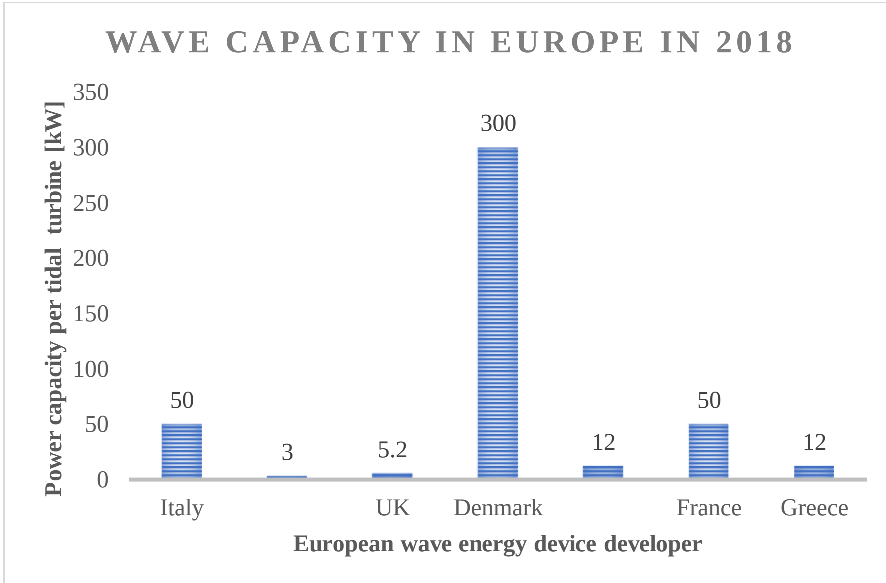


Figure 7 suggests that there is a large range with devices providing 3 kW to 100 times more power output. The largest power capacity is found in Denmark with 300 kW, followed by France and Italy with 50 kW each. The range highlights that there is no convergence on wave device design because natural resources differ per environment. The variance in capacity output informs the uncertainty of calculations carried out in the research and why estimates have to be made to inform future projections in Australia.

The device capacity factor is an important measure to calculate annual power generation for a project and thus potential for commercial market (Table 48).

Table 48: Capacity factors for tidal and wave energy referenced by different literature sources.

ORE Technology	Capacity Factor range	Literature Reference
Wave	30%-43%	Behrens et al., 2012
	20%-35%	Ocean Energy Council, 2018
	25%-40%	Seanergy, 2016
	35%-40%	OES, 2015
Tidal	30%-40%	Seanergy, 2016
	30%-40%	OES, 2015

Based on the capacity factors listed in Table 48, an average value of 35% is chosen for both tidal and wave energy to calculate the technical potential related to an industry. This way the potential capacity output of electricity can be summed as ORE where the type of device better suited to the industry can be determined specifically with future in-depth research per company case or marine sector (e.g. aquaculture).

The following section analyses the context of renewable energy, ocean sources and sustainability pathway for each marine sector. With the help of literature sources, interviews and quantitative data calculated, the ORE technical potential is the estimated per sector. Of the energy consumption data found per company, the technical potential is based on the electricity and/or fuel data of the sector. Then with the carbon emission factor, the potential emission abatement can also be calculated, based on the found ORE power uptake estimated ranges.

2) Aquaculture

Renewable energy (incl. ocean)

The following descriptive paragraphs inform the potential for renewable energy as well as ocean sources to help progress the sustainable energy pathway in the Aquaculture sector of Australia's BE. The information combines online sources and responses pertaining to the following three interview questions:

i) "Does the Aquaculture sector have strategies to reduce energy costs or demand?"
ii) "Do you consider RE as an opportunity for the Aquaculture sector?"
iii) "Do you consider ORE as an opportunity for the Aquaculture sector?"

The literature confirms that the majority of aquaculture companies, specifically Huon and Tassal, are placing engineering efforts to carry out salmon farming operations offshore to help reduce costs from the supply side and emissions (Huon 2019; Tassal, 2019). Both Huon and Tassal are collaborating with the BECRC to expand research and knowledge for expanding toward high energy ocean sites.

Huon has installed an offshore salmon farming site in Storm Bay because there is an optimal combination of wave energy action and water flow (2019). Huon is also concentrating engineering efforts to increase resource efficiency. For example, the company recognizes that high technology monitoring systems are important to increase consistency of operations and lower overall environment impact (Huon, 2019). In this case, it can be argued that the infrastructure is adequate to include high technology systems that could monitor weather conditions and wave action in high energy sites (i.e. offshore). With regards to renewable energy integration Huon is looking to electrify their systems. The interviewee shares that to replace diesel use on vessels there would need to be a considerable change of operations (Environmental Compliance and development manager, personal communication, May 5, 2020).

Tassal contributes to the BE research funding as the business provides the infrastructure and site usage for R&D in the transition to offshore farming and marine renewable energy (2019). In the 2018 sustainability report, Tassal writes a long-term goal (i.e. 2023-2030) to develop higher energy sites for farming based on the outcomes of research and consultation studies. Tassal is performing investigations to improve Remotely Operated Vehicles (ROV) technology needed in monitoring programs for fish performance and environmental management (2019).

For Petuna, there is no evidence of a sustainability report published online that would provide data on energy use as well as the potential for improving system efficiency and related operations for salmon culture. Rather, the sustainability commitment relates more to environmental management (e.g. reducing waste) so it is difficult to interpret the potential for RE as well as for tidal and wave alternative power source (2020a).

The representative of Pitt&Sherry confirms that a slowing factor for ORE adoption is that farmers express interest in new equipment and in reducing costs, more so than a concern for energy consumption (Energy & Sustainability Engineer, personal communication, 25 March 2020). In some states (e.g. Victoria) grants are provided to fish farmers to pay for energy audits, but the cost issue remains as the farmer must incur the payment for a pre-feasibility study (i.e. AU$30,000) and full feasibility study (i.e. AU$50,000 – AU$100,000). To receive financial support, the manager has to make a business case showing the potential to mitigate energy price risks and means to obtain a reasonable payback time (Energy & Sustainability Engineer, personal communication, 25 March 2020). The high costs and required detailed information create an important hurdle to be overcome by aquaculture stakeholders, prior to even strategizing for potential low carbon alternative, specifically ORE.

To put into perspective the potential for ORE in Australia the following table illustrates the Strengths, Weaknesses, Opportunities and Threats (SWOT) from representatives at Tassal – presented in the AOEG Ocean Energy Market Development Summit held in December 2019 in Sydney, Australia (Table 49).

Table 49: SWOT assessment of ocean energy from an aquaculture company perspective (Evans & Berrenger, 2018).

Strengths	**Weaknesses**	**Opportunities**	**Threats**
Proven power requirements	Reliable power sources	Alternative power sources	Exposed high energy environment
Established industry	Diesel is high reliability and low risk	Sustainability footprint	Increased availability of biofuels
Present investment and growing capital	Geographical exposure of sites	Diversification of energy usage	Risk of system operation failure
Strong push for expansion	Industry energy demand & requirements of operations	Integration of solar, wind, wave and tidal energy	
Proximity to wave & wind energy	Time frame of risk assessment & concept proof		

The drawbacks presented in Table 49 align closely with the barriers discussed in the O&G sector, notably the need for a consistent, high volume power source and that diesel is the most affordable, least risk fuel. The opportunities for ORE match discussion in interviews (written throughout results) where companies regard the positive aspect to integrate multiple renewable energy sources for reducing the carbon footprint. The main risk highlighted throughout conversations with represented marine sectors remains the harsh, extreme weather offshore environment and reliability of tidal and wave power generation to meet system operation requirements.

Technical potential calculation

The technical potential is calculated based on the energy demand, electricity, and diesel demand values found in SQ1.

The technical potential will be calculated based on the energy demand and diesel demand extrapolated values according to the citation by Hemer (2019) to keep consistency with the research programs invested by the BE CRC (Table 7). Considering Dr. Hemer is one of the program leaders of the research areas, the results found here can be directly applied and utilised by the cooperative.

Table 50: Summary of calculated energy usage expressed in GWh in 2019 and 2020 for Australian Aquaculture companies interviewed (Author's own). The values in TJ can be found in Annex 10, Table L.

Company	Financial Year	Energy Demand [GWh] (Hemer, 2019)	Diesel Demand [GWh] (Hemer, 2019)	Total Energy [GWh] (Troell. et al., 2004)
Tassal	2019	128.1	57.6	857.8
	2020	140.4	63.2	940.5
Huon	2019	75.0	33.7	502.0
	2020	109.0	49.0	729.7
Petuna	2019	24.0	10.8	160.4
	2020	29.8	13.4	199.5

Then, the ORE potential is calculated according to the follow equation.

Equation 5: ORE potential for industrial sectors of Australia's BE

$$ORE\ power\ potential\ [MW] = \left(\frac{industry\ energy\ demand}{year} * c.f \div \left[\frac{8760\ h}{year}\right]\right) * 10^3$$

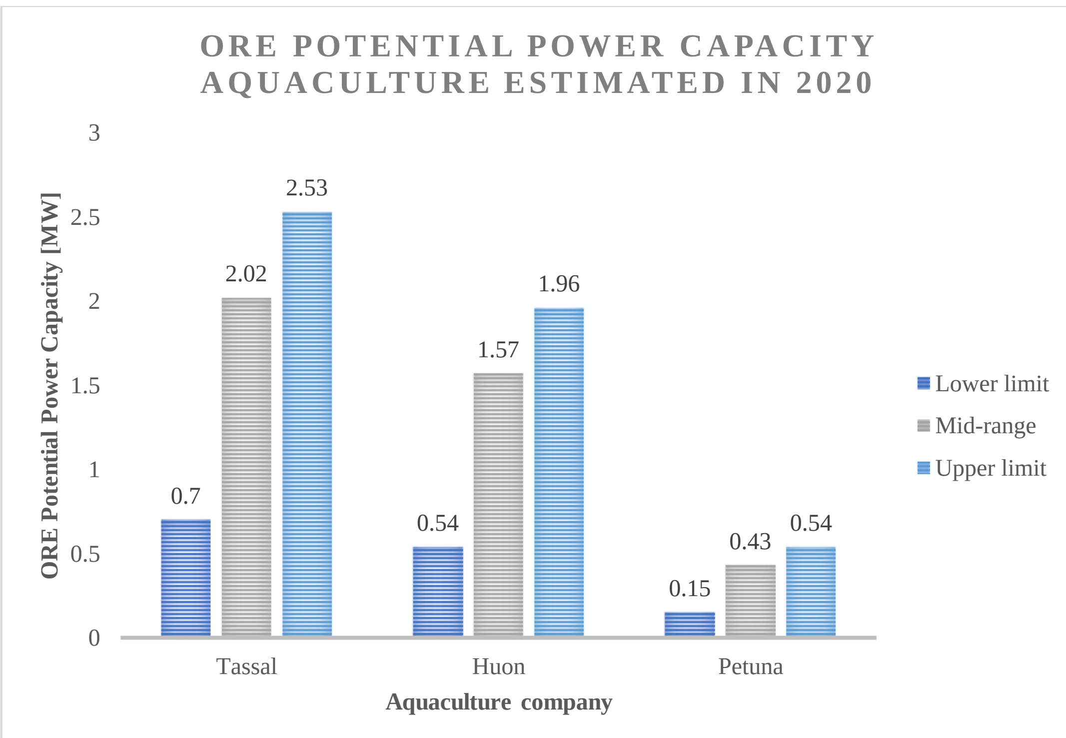
Where;

$$capacity\ factor\ (c.f.) = 0.35$$
$$h = hours$$

To create a range for ORE potential for each aquaculture company, the upper limit (i.e. optimistic estimate) suggested is if all diesel demand (45%) was displaced by tidal or wave power generation. The mid-range is suggested as the share of electricity out of total energy use published by Tassal in the financial year 2017, which amounts to 36%. The lower limit (i.e. conservative estimate) suggested is where electricity, fuel is 12.4% of the total energy demand (Troell et al., 2004). These limits can be suggested under the form of different energy transition scenarios for the aquaculture sector.

The power generation capacity potential from ORE in Aquaculture for the year 2020 is represented in figure 8 (Data for 2019 can be found in Annex 10, Table M, Figure L).

Figure 8: Potential power generation for tidal and wave technology calculated in 2020 for Australian aquaculture companies (Author's own).



Petuna has a lower energy consumption than Tassal and Huon; However, the anticipated growth of activities and production volume, estimated at 24% annual increase from FY2019 to F2020, is likely to follow a growing trend in upcoming years and enable a significant amount of electricity usage that could be replaced with ocean technology (Table 51). Table 51 shows the annual percentage increase of ocean power potential from 2019 to 2020 for the aquaculture companies from a conservative estimate to a high estimate.

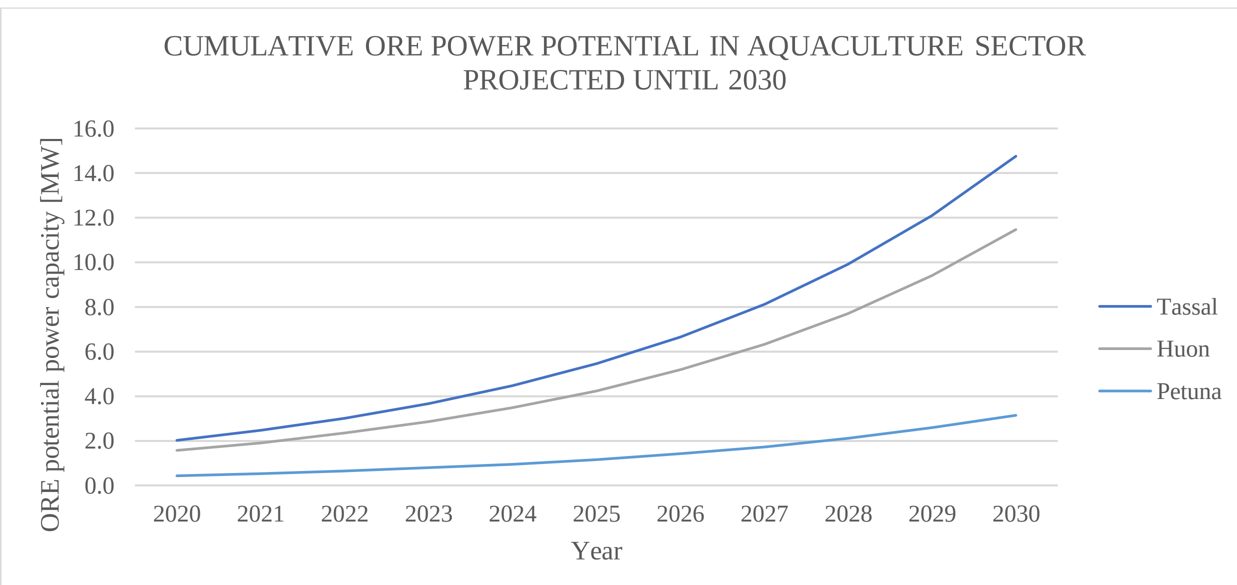
Table 51: Annual change in ORE power potential uptake in Australian Aquaculture sector (Author's own).

Company	Lower limit	Mid-range	Upper limit
Tassal	11%	10%	10%
Huon	17%	49%	61%
Petuna	3%	8%	11%

The growth in ORE power capacity is largest at Huon ranging between 50% to 60% considering the mid-range and optimistic estimate, respectively, of displacing fossil fuel based electricity. The higher percentage potential is because the total energy usage at Huon increases by 45% from 2019 to 2020, nearly double that of Petuna's and four times that of Tassal's energy (Table 22). Huon and Petuna follow a similar estimated power capacity potential increase (10%) of ORE sourced for electricity use from 2019 to 2020 across all adoption scenarios.

The average of the annual mid-range power potential uptake of all three companies is 22%; this value is used to calculate the rate of ORE uptake projected and cumulative from 2020 until 2030 for Aquaculture (Figure 9). For simplification of calculations this growth rate of 22% ORE uptake is also applied to the O&G and Ports sector analysis.

Figure 9: Cumulative ORE power potential uptake in Australian aquaculture companies projected from 2020 to 2030 (Author's own).



In Figure 9, the potential ORE capacity per company is represented with the same annual growth rate in device deployment despite company size and production activity. The relative electricity use is represented within the mid-range ORE power potential value, that is 36% of total energy use. In 2022, Tassal, Huon and Petuna, have an ORE power capacity potential estimated at 3.0, 2.3, and 0.6 MW, respectively. By 2025, the potential amounts to 5.5, 4.2, and 1.2 MW for Tassal, Huon, and Petuna, respectively. By 2030, both Tassal and Huon surpass a 10 MW capacity and Huon stands at 3.1 MW of ORE power source for their electricity use.

The increase in ORE potential uptake for electricity aligns with the energy growth trend calculated in SQ1 for each aquaculture company (Annex 10, Tables K, L, M).

Emission abatement

Pelc (2014) provided access to the seafood carbon emissions tool (Seafood watch, 2020). According to the portal, Atlantic salmon that is farmed in recirculating tanks have 2.3-4.8 kg CO_{2e} per kg of fish. In table 52 the lower limit (i.e. conservative emission output) considers 2.3 kg CO_{2e} per kg of fish, the higher limit estimates (i.e. pessimistic emission output) 4.8 kg CO_{2e} per kg of fish and the mid-range is the average of the lower and upper limit. The emission equivalent value range aforementioned is used to estimate the emissions for each aquaculture sector in 2019 (Annex 1). The average of emissions and total emissions for all three aquaculture companies is displayed in Table 52. The year 2019 is chosen for better accuracy because the volume production of each company is directly sourced from the literature for that year, whereas for the year 2020 emission output would be based on estimated energy demand calculated.

Table 52: Calculated average and total emission for Aquaculture industries in 2019 (Author's own).

FY2019	Emission output range (Mt CO2e)		
All companies	**Lower limit**	**Mid-range**	**Upper limit**
Average emissions	43.7	67.4	91.2
Total emissions	131.1	202.3	273.6

The weight of the fish used is the production volume of each company (Table 21) in which case HOG weight is estimated as the same as kilogram weight of fish on the carbon emission tool site since no specifications are made. The annual rate of change of emissions aligns with the growth trend in production volume of each company (Table 22). Emissions will grow significantly by 2030 if production growth continues on the same trend.

The conservative and pessimistic emission output estimate carbon factor values are used to calculate potential abatement in 2020 for each company. The year 2020 is chosen to align with the ORE technical potential calculations made previously. Calculations show that in Aquaculture in 2020, there is a potential high emission abatement for electricity of 1183.5 kt CO_2, 918.8 kt CO_2 and 251.2 kt CO_2 from placing ORE technology at Tassal, Huon and Petuna, respectively (Figure 9) (Annex 10, Table N). The pessimistic scenario amounts to 28% of emissions compared with estimated fossil fuel electricity sourced emissions in Aquaculture. The conservative estimate of emission abatement for electricity for Tassal, Huon and Petuna in 2020, amounts to 909.3 kt CO_2, 705.9 kt CO_2 and 193.0 kt CO_2, respectively. In the case that diesel input sources are replaced with ocean resources, the carbon emission abatement that can be achieved is 25% higher across both the lower limit and higher limit range than the abatement estimated from electricity (Annex 10, Table O).

Since emissions correlate with production volume, a linear growth in production results in a linear increase for carbon emissions as well in each company. No detailed information was found on the future of the Australian aquaculture industry, past the year 2020, in terms of the rate of production output that would help estimate the fish total weight volume, and thus reduced emission output from deploying ORE in the sector for the next decade. Rather information is specific to the future economic contribution of aquaculture to Australia from local to international market.

3) O&G

Renewable energy (incl. ocean)

The following descriptive paragraphs inform the potential for renewable energy as well as ocean sources of energy pathway in the O&G sector of Australia's BE. The information combines online sources and responses pertaining to the following two interview questions:

i) "Do you consider RE as an opportunity for O&G industries?"
ii) "Do you consider ORE as an opportunity for O&G industries?"

The question on 'strategies to decrease costs/energy use' was not asked because of the nature of the O&G sectors as an intensive fossil fuel energy source and subsequent elevated carbon footprint. There are confidentiality issues related to the topic. Rather the question was posed in order to understand the strategies for sustainability in the O&G sector, discussed further down.

Companies are taking more steps to improve their environmental management and social responsibility practices. The main driver for energy management is the regulation, cost, reputation and need to maintain production. Given the size of the industry the financial loss in a case of lost production is very risky so companies care to optimize processes at all times to avoid production downtime (Vamer, 2005). Renewable energy is an opportunity for O&G companies that are dependent and have energy application on site. In Australia, ORE is low on the radar for O&G industries because the general perception is that it is in the R&D phase and is not yet commercialised. Businesses are not willing to take the risk to support R&D, rather O&G companies will choose proven and mature renewable technologies to ensure power generation (Corporate development manager, personal communication, June 12, 2020). Another interviewee shares a similar point of view that the drawback for considering ocean energy is that as of today the technology is in an immature phase of development for which O&G companies are no willing to take 'venture capital' risks (Senior Petroleum Engineer, personal communication, May 2, 2020). Reliability is an important driver for decision- making and would be the next question even if the technology became commercially viable.

Australia depends a lot on earnings from export to other countries, which explains the relative lack of incentives present for RE (such as a direct tax on carbon). The government is unlikely to stop bulk production of iron ore, LNG, and coal for export, since these primary materials account for the three out of the top four export earnings for Australia (Energy & resources Executive Director, personal communication, June 4, 2020).

The focus for an O&G company is competition and cost, so decisions are made based on cost rather than where the energy comes from. Beaubouef (2020) writes that offshore drilling contractors care to reduce fuel consumption and increase fuel efficiency. Furthermore, to reduce their carbon footprint, companies are deploying hybrid power systems and battery technologies on the rigs.
In the case of ocean energy, it is a produced in a dynamic, high energy and unpredictable environment which contributes to the high cost of the technology. The representative from Atteris highlights that there is a need for reliable technology that is less expensive (Asset Lifecycle Manager, personal communication, 25 March 2020).
Past ocean energy demonstration projects have led to disappointments for the O&G industry because several wave companies have gone into receivership (Energy & Resources Executive Director, personal communication, June 4, 2020).

According to the interviewee representative at Woodside, renewables are definitely an opportunity and the company is researching blue and green energy to help reduce high CO_2 emissions from the energy mix. At present, the main renewables considered are wind and solar technologies because these are well suited to the Australian climate for generating electricity onshore and offshore (Senior Petroleum Engineer, personal communication, May 2, 2020). There is a need for larger scale project with tidal and wave technologies to help meet the long-term goals of energy demand within (O&G) industries. O&G companies need a secure level reliability of the technology because operations run 24 hours a day, where pausing operations would cause serious economic consequences. In addition, the slow adoption of tidal and wave can be explained by the limited understanding on the possibility to link a tidal device turbine to a subsea operation platform (e.g. FPSO) (Senior Petroleum Engineer, personal communication, May 2, 2020).

Since no interview were carried out with Conoco Phillips nor Arrow energy, there is no direct information that can be explained and analysed on renewable energy pathway and integration of ocean renewable energy.

Summary
The majority of companies respond that there is a good opportunity to implement renewable energy throughout operations, particularly solar because of the reliability and affordable market electricity price. The NERA representative explains that initiatives in renewable energy adoption is mostly pushed because of CO_2 footprint, and scope 1 & 2 emissions. This is confirmed with Arrow Energy writing that the company values the environment as a mean to produce cleaner energy and is working to meet both domestic and international demand of low-carbon burning fuels (2020) and Conoco Phillips sharing that technology will play an important role in addressing GHG emission reduction and achieving lower emissions intensity (EI) of operations. Furthermore, the company has focused near-term technology investments on reducing costs and emissions where possible (ConocoPhillips, 2020a).

For ORE integration, the majority of companies interviewed share that there is limited opportunity because of capital risks, costs and the need for further development as well as larger scale project. There are large capital investments in the pipeline system to link offshore operations to the mainland, with a current value of A$4.5 million per km and over 2000 km of pipelines under design in Australia (ATC, 2013). The prior mentioned infrastructure expenditure could be reverted to installing devices locally.

The Atteris company representative explains that there is the potential to decommission current O&G platforms with tidal power (Asset Lifecycle Manager, personal communication, 25 March 2020). As a matter of fact, an O&G company has deployed Ocean Power Technology (OPT) device to harness electricity from wave energy and serves as an example that ORE is suitable for offshore operations (Marine Energy, 2018a). The PB3 is the first power buoy device that acts as a battery charging station for AUV's to enable remote inspection and environmental monitoring (Marine Energy, 2018c). Vessel services offshore include construction support, drilling operations, tug & barge operations, maintenance and repair services, and supplies (Guardian offshore, 2020). The vessels could serve as a platform to install OPT devices that can be used for battery charging to then power subsea equipment, sensors and functioning of ROVs (Marine Energy, 2018b).

Technical potential calculation

With the information from the literature, the analysis from interviews and energy demand, the technical potential is calculated based on the electricity use and diesel demand values found in SQ1.

To calculate the ORE power potential for the O&G sector, three of the five companies interviewed are represented. Given the lack of available data on the electricity use per company, the value is extrapolated for each company based of Woodside's electricity demand out of total energy consumption, that is 0.03% (Table 53). Then ORE potential is calculated according to equation 5. As the energy use is in the folds of TJ and is estimated to increase in upcoming years confirmed by the approval and investments in exploration and drilling projects discussed prior, it still allows for a measurable displacement of fossil fuel sourced electricity with ocean sources as inputs for O&G offshore operations.

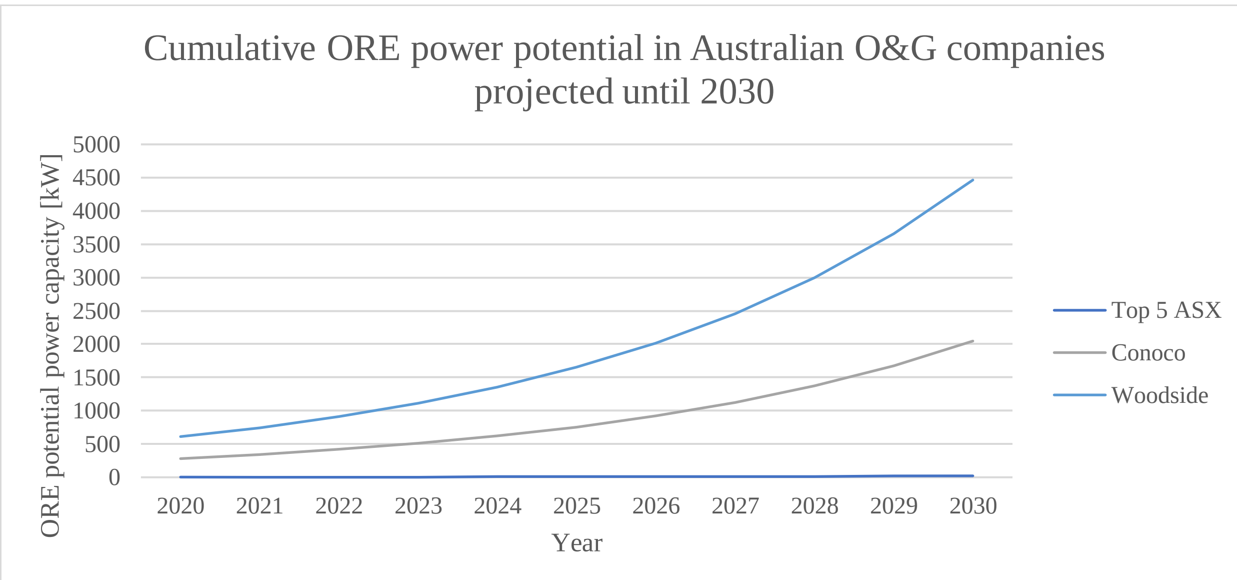
Table 53: Potential power generation for tidal and wave technology calculated in 2018 for Australian O&G companies investigated (Author's own).

Energy source (2018)	**Top 5 ASX**	**Conoco**	**Woodside**
Energy/fuel consumption [TJ]	679	64,358	140,433
Electricity use [GWh]	0.05	4.71	10.28
ORE Potential [kW]	**1.99**	**188.19**	**410.64**

The table above represents ocean resource potential in kilowatts for three O&G companies in 2018. However, with the benefits of implementing an integrated and multi-sourced energy system, the suggested potential calculated in Table 53 can make a business case. Woodside holding the largest energy consumption, accordingly has the largest electricity use that can be displaced it with tidal or wave technology. Conoco has almost 200kW of ORE potential. The anonymous has a negligible amount of potential given its smaller size compared to Conoco and

Woodside. The following figure displays the cumulative power potential for the three O&G companies listed in the table above based on a 22% deployment growth each year ocean devices per company (i.e. to match the calculation made for Aquaculture).

Figure 10: Cumulative ORE power potential uptake in Australian O&G companies projected from 2020 to 2030 (Author's own).



The estimated ORE for electricity use amounts to 3kW, 280 kW and 611 kW for the anonymous company, Conoco and Woodside respectively. By 2023 Woodside can reach over 1 MW of energy from ORE and the same holds for Conoco by 2027. Given the small size of the top 5 ASX company, estimated cumulative potential is 22 kW by 2030. For the remaining two companies, Conoco can establish 2 MW and Woodside can obtain 4.5 MW.

The ORE potential is relatively small to the company's overall energy demand, so it is a feasible renewable energy project that can be integrated over periods of time (e.g. every two years).

Emission abatement

Table 54: Greenhouse gases emission sources of Australian O&G companies in 2018 (Arrow, 2015a, p.81; XXX, 2018, p.36; Conoco, 2018; Woodside Sustainability Hub, 2020).

	Emission source [ktCO2e] in 2018		
	Scope 1	**Scope 2**	**Total GHG**
Arrow	-	-	47.1
Top 5 ASX	43.8	0.37	44.17
Conoco Phillips	-	-	109
Woodside	9767	8	
Carnarvon	-	-	-

Table 54 shows the lack of available data for O&G companies on GHG emissions. The data generated per aquaculture company is referenced to estimate the carbon emission abatement (Dept. Envr, 2017). Based on the previously calculated ORE power generation potential (Figure 10) the suggested upper limit and lower limit range for carbon emission abatement is measured with the carbon factor of 51.4 kg CO_2/ kWh and 66.9 kg CO_2/ kWh, respectively (Table 55). The emission abatement is calculated in 2020 from extrapolation of ORE sourced electricity (in GWh) since 2018 (Annex 11, Table S).

Table 55: Calculated emission abatement potential from ORE uptake in O&G sector in 2020 (Author's own).

Company	**Emissions abatement from electricity [kt CO2]**	
2020	Lower limit	Upper limit
Top 5 ASX	1.3	1.7
Conoco	126.1	164.2
Woodside	275.2	358.2

Calculations show that in O&G sector in 2020, there is a potential high emission abatement for electricity of 1.7 kt CO_2, 164.2 kt CO_2 and 358.2 kt CO_2 from placing ORE technology at Top 5 ASX, Conoco and Woodside, respectively (Annex 11, Table T). The estimated lower range for emission abatement is about 25% fewer emissions abatement by installing ORE technology than the upper range. While the company Woodside is exemplified above for its efforts in reducing emissions by source in 2018, these percentage reductions are not factored in for emission abatement to maintain simplicity of calculations across all companies. Further, the emission performance at Woodside is not applied directly to the remaining companies, to reduce the range of uncertainties and assumptions made considering the multiple differences of operations in each company representing the O&G sector.

4) Ports

Renewable energy (excl. ocean)

The following descriptive paragraphs inform the potential for renewable energy pathway in the port sector of Australia's BE. The use to first understand the industry's mindset on renewable energy is it can then help form the context for ocean energy specifically. The information combines online sources and responses pertaining to the following three interview questions:

i) "Do you consider RE as an opportunity for the port?"
ii) "Does the port have strategies to reduce energy costs or demand?"
iii) "What are the motives/strategies for sustainability?"

Then the technical potential is calculated for uptake of ORE in the ports by relying on information found in the literature, the analysis from interviews and energy demand, and the electricity use and diesel demand values found in SQ1.

Brisbane

The main driver for green energy is largely emission reduction, with efforts for improving efficiency initiatives internally. PI has installed one of the largest rooftop solar project with 100 kW solar system, or 259 high efficiency solar panels. The focus has mostly been on solar because of its cheap cost and adequacy for the port's spatial layout. The port is building a new cruise ship terminal where a car park will be refurbished to install solar panels with an expected capacity of 800 kW by August 2020 (Envr. manager, personal communication, April 4, 2020). The port is financing the project themselves with some government assistance with the subsidy for solar from the Renewable Energy Commitment.

Broome

PB is proactively seeking ways to increase investment in and adoption of renewable technology, which at the moment is solar (PBPL, 2019). There is no plan for reducing energy usage at this stage, though some strategies have been identified to reduce energy use. PB shares investment in infrastructure is likely necessary to meet technical maintenance of RE or to cool down batteries (i.e. in the case of solar) (HSE manager, personal communication, May 15, 2020).

Esperance

PE has made little advancements in RE because the port is locked in an energy contract. There is collaboration between the environmental, electrical and engineering teams to look at alternative energy sources. The commercial team is negotiating for a new contract that would enable 1MW of RE power. The envr. advisor is working on a rooftop solar project, because of available north facing large roof areas ideal for panels, though there are issues with supporting the weight of panels on the intended shed structure (Envr. manager & envr. advisory, personal communication, May 12, 2020).

Gladstone

There are no current mandated requirements or set targets, rather PoG uses SDGs as guidance for sustainability (Sust. specialist, personal communication, January 30, 2020). PoG has the vision to adopt renewables at a small scale (e.g. solar) because of available and affordable electricity from the grid (Sust. specialist, personal communication, January 30, 2020).

Townsville
PT is working on a business case to identify cost benefit ratios of current energy consumption with those that can be converted to solar compared with electricity dependence on the grid. PT is looking to joint ventures with solar farm to gain direct energy access (Manager strategy & sust., personal communication, April 2, 2020). PT is in the early stages of considering H_2 as a potential energy source because the QL government is focusing on R&D in H_2, with a committee of industry and energy providers that begun a roadmap strategy for the next 5-10 years (Manager strategy & sust., personal communication, April 2, 2020).

In summary, ports are considering the potential for alternative RE but securing enough investment is difficult because grid-connected electricity is available at a cheap cost. The majority of ports (ie. Brisbane, Broome, Gladstone, Townsville), are primarily engaging in solar energy to diversify their energy mix and increase overall renewables in the energy mix. The reason solar potential is so high is because the technology is proven and there is little maintenance (General manager innovation and strategy, personal communication, 19 March 2020). The consultant representative of Pitt&Sherry shares that companies consider electrifying their processes by using solar because of its lower installation costs, or signing Power Purchase Agreements (PPAs) with a renewable energy farm to mitigate long term risk of energy costs (Energy & Sustainability Engineer, personal communication, 25 March 2020).

Ocean Renewable Energy

The following descriptive paragraphs inform the potential for ocean renewable energy, tidal and wave technology integration in Australian ports. Information is sourced from online sources and responses pertaining to the following interview question:

i) "Do you consider ORE as an opportunity for the port?"

Brisbane
PI has been speaking with Eco Wave Power, a Swedish company, to consider a pilot project. The process is slow because the technology has not reached a commercial level and has a much higher cost especially when compared to that of solar. The interviewee shared the following issues surrounding ORE technology (Envr. manager, personal communication, April 4, 2020):

- the engineering aspects
- attachment to a (port) structure
- potential damage the rock wall
- impacts of extreme weather events
- connecting to power grid
- frequency of the power generation
- distribution of energy and facility infrastructure

There has been conversation with the sust. specialist at the PoG to understand the viability of tidal turbine technology from PoG pilot study with MAKO tidal turbine company.

Broome

PB has potential for installing tidal turbine technology; There is on average 3.6m tidal levels and streams where "the tidal range is 10.3m, with a mean spring tide range of 7.7m" (KPA, 2020, p.11). The interview shares that there could be great benefits for tidal or wave technology but Investment in infrastructure is likely needed for installing devices (HSE manager, personal communication, May 15, 2020).

Esperance

PE records data for weather, waves, current and tides for its different locations. There are two locations, notably the Beacon 2 and Harbour site that have evidence of tidal and wave resource (Southern Ports, 2020). The interviewee shares that the tides are small so alternative options may be assess based on viability of wind or wave energy (Envr. manager & envr. advisory, personal communication, May 12, 2020). PE can collaborate with the Wave Energy Research Centre (WERC) at the UWA (University of Western Australia) campus at Albany.

Gladstone

PoG partnered with MAKO Turbines for a tidal turbine demonstration deployment (WPSP, 2018). The demonstration project is a pioneer for placing turbines using port infrastructure and serves to share the learning from alternative RE and how these can be integrated in the existing energy mix, of GPC in this case. The interviewee confirms that there is no clearly defined process in Australia and in Queensland for installing tidal turbines, or, an approach on how to interact with regulators. Solar and wind have reached commercial competency and are grid connected, so the government is incentivizing it, rather than investing on finding answers on how to bring a new (tidal) technology forward. The interviewee shares three hurdles industries have to overcome for investing in ORE are:

1. Federal and state legislation
2. Competition of other renewables –commercial state and large electric supply capacity
3. Scale – potential interaction of turbines / cabling network

Furthermore, businesses have not considered ORE because of a lack of knowledge and missing preliminary information on the following:

- Facilitating the technology
- Source of finance to cover costs (e.g. installation., infrastructure, feasibility study)

(Sust. Specialist, personal communication, January 30, 2020).

Townsville

PT several types of waves, namely swell waves, distant sea waves, and local sea waves. The wave energy arrives at the ocean entrance of the Townsville port, namely, Breakwater Cove Waterway (Coastal Engineering Solutions, 2007). Though, PT considered tidal energy, after talking with the PoG on the MAKO project, but PT has dismissed it as opportunity due to concerns on the reliability and functioning of the technology (Manager strategy & sust., personal communication, April 2, 2020). Compared to solar which has been tried and tested, tidal needs to undergo a learning curve for a cost reduction and comparable scale of power generation (e.g. Gigawatts).

The interviewee shares that ports around the world have a very limited knowledge of OREs. Ports needs energy that is consistent, cheap and clean (Manager strategy & sust., personal communication, April 2, 2020).

Technical potential calculation

The energy mix data published for the financial year 2019 by the Port of Brisbane is used as a baseline for the three remaining ports (excluding Broome as there is no available data) because it is the only source that reported recent quantitative sustainability information (Table 33). The values in blue in Table 56 are the energy values derived from PI's energy mix (i.e. 91% diesel, 8% electricity, and 1% solar) (pBPL, 2019, p.33).

Table 56: Extrapolated energy data per source for four Australian Ports interviewed (Author's own).

Energy source [GWh]	Brisbane	Esperance	Gladstone	Townsville
Total Energy	40.06	157.67	254.57	7.22
Total Electricity	3.21	12.61	20.37	0.58
Diesel	36.58	143.95	232.43	6.59
Renewable Energy (solar)	0.40	1.58	2.55	0.07

In table 56, the electricity own use at PE is used for the calculation rather than the total electricity as that includes lease holders. Energy own use may be easier as a first stage approach for ORE uptake to reduce energy and carbon footprint (e.g. scope 1 and 2 emissions). The energy demand values equivalent in TJ can be found in Annex 13, Table AD.

ORE potential power generation is calculated for the ports and is illustrated in Table 57, rather than in the bar graph because some of the potential values are too small to be seen clearly. Similar to the aquaculture sector, the upper limit considers electricity, which is 8% of total energy consumption is displaced by ORE technology. The lower limit considers the equivalent quantity of renewable energy to the amount of solar production energy, which is 1%, as the ORE potential (Table 33).

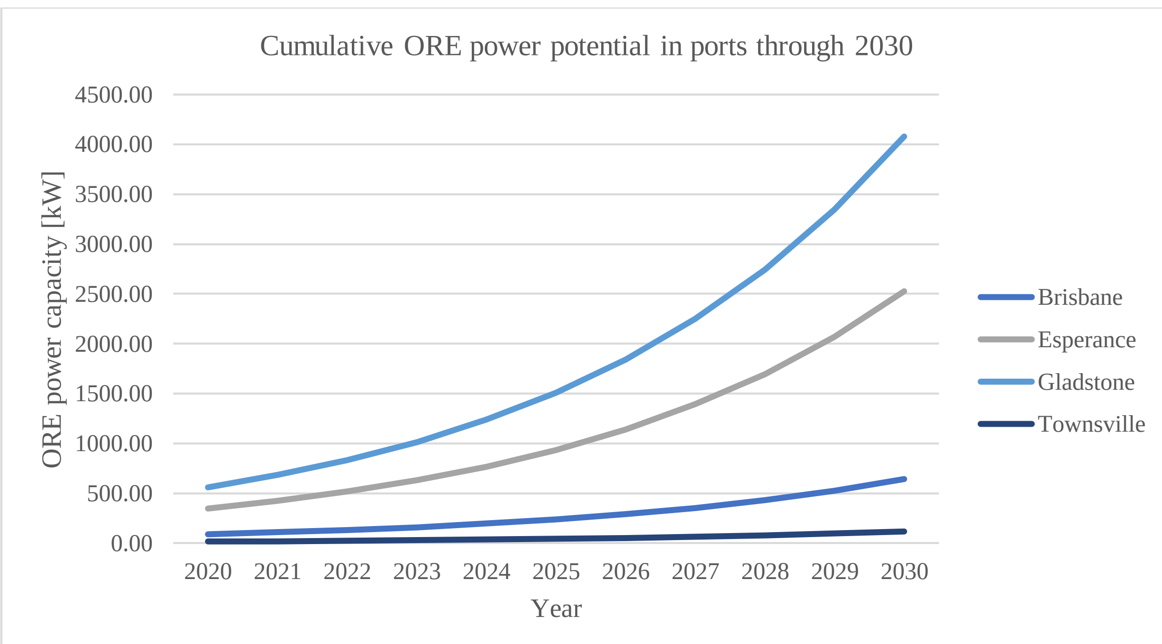
Table 57: Estimated range of ORE power potential for Australian Ports in 2019 (Author's own).

ORE potential Power [kW] in 2019		
Port Name	**Lower Limit**	**Upper Limit**
Brisbane	16.01	128.06
Esperance	62.99	503.98
Gladstone	101.71	813.74
Townsville	2.88	23.08

The power potential sourced from tidal energy in this case is in the folds of kilowatts. Ports are more likely to install tidal turbines because their geographical location coincides with available tides. The significant lack of examples and methods to calculate tidal power potential in the literature raised uncertainty on the assumptions made to estimate tidal power calculations. To avoid presenting inaccurate data, it was decided to not carry out calculations to measure a potential tidal power generation for each of the ports investigated. Rather, collaborating with an expert, engineer in tidal stream flow and wave energy would be valuable for calculating precisely the power potential relevant to each port location. Tidal times charts for each port can be found online on the Marine Science Australia page (Annex 13, Figure K). The CSIRO published a wave energy atlas displaying wave data in Australia which can also be used as a source of reliable information for precise calculations.

To make a similar projection as the case of Aquaculture and O&G, an annual growth in ORE potential deployment of 22% is taken into account. The growth in deployment, power capacity of ORE is applied to the average of the lower and upper limit ORE potential, meaning about 5% of electricity, energy use is displaced from fossil fuels to tidal or wave technology for the four ports in (Table 57). The average is taken as a way to homogenize outlier points.

Figure 11: Cumulative ORE power potential uptake in Australian aquaculture companies projected from 2020 to 2030 (Author's own).



The estimated ORE power potential for electricity use in 2020 amounts to 88 kW, 346 kW, 558 kW, and 15 kW for PI, PE, PoG, and PT, respectively. By 2025, the PoG reaches over 1.5 MW of ORE power potential and over 4 MW by 2030. PT has the lowest potential reaching a maximum of 115 kW by 2030, and PE has nearly 2.5 MW of electricity that can be sourced from tidal or wave devices in 2030.

Emission abatement

There is limited quantitative data on carbon footprint of port activities because of the difficulty to draw a boundary for which activities to account emissions. Ports have numerous vessels coming and going, for which in itself a vessel holds a significant carbon footprint and energy demand when passing through the port to deliver goods and continue to the next destination. Then a study of emissions needs to focus on scope 1 and 2 sources. In this case a carbon factor for fossil fuel sourced electricity is compared with renewable source of electricity generation to account for the potential abatement in ports (Table 58).

Table 58: Calculated emission abatement potential from ORE uptake in O&G sector in 2020 (Author's own).

Port	**Emissions abatement from electricity [Mt CO2]**	
2020	Lower Limit	Upper Limit
Brisbane	4.52	5.88
Esperance	17.78	23.14
Gladstone	28.70	37.36
Townsville	0.81	1.06

Calculations in table 58 show that for Ports in 2020, there is a potential high emission abatement for electricity of all ports estimated at 67.44 Mt CO_2. The estimated lower range for emission abatement (i.e. 51.4 kt CO_2 per kWh) is 77% of the emissions estimated in the pessimistic scenario or 52 Mt CO_2 in 2020 for all four ports aggregated.

5) Consultancy perspective

Interview responses with consultancies help shed light on the overall energy usage, as well as the perspective around sustainability and (O)RE adoption within marine industrial sectors of Australia's Blue Economy. The following paragraph integrates discussions with renewable energy consultancy representatives to help summarise all the points raised above, that is, energy usage of industries, opportunities and barriers for renewable energy, and the take away message for ocean technology within industries.

The variation in energy demand per industrial sector can be explained by the fact that energy usage and electricity demand of industries is dependent on processes per sector (Energy & Sustainability Engineer, personal communication, 25 March 2020).

The constraint for ORE in O&G is that there is a need for 100% reliable energy for hydrocarbon production, and for now the current power output of ORE is too small especially for offshore (Asset Lifecycle Manager, personal communication, 25 March 2020). The representative of NERA confirms that there is unanimous concern of ORE technology reliability, maintenance, and potential for MW output to meet base load requirements, especially in O&G industry (General manager innovation and strategy, personal communication, 19 March 2020). Another constraint for the development of tidal and wave technology is that the infrastructure and facilities offshore need to be in place and have resiliency given the difficult environment (General manager innovation and strategy, personal communication, 19 March 2020). The representative of ORE Catapult mentions that there is no standard way to install or deploy ORE, especially compared to what is establish in wind energy. The difficult natural environment lengthens the testing in situ, and so the ability to reach a significant commercial scale (Analysis & Insights and Senior Mng. Researcher, personal communication, 18 March 2020). Industries will show compliance if there is a policy to abide to and it can improve the business (Energy & Sustainability Engineer, personal communication, 25 March 2020).

The main challenge in the marine energy industry is for ORE companies to prove that they can generate a more predictable source of renewable energy. Interviews with consultancies confirm that there is a need for financial support because investors will invest based on Return on Investment (ROI) and want to make sure the investments can be de-risked by government funding (Analysis & Insights and Senior Mng. Researcher, personal communication, 18 March 2020). One of the strongest barriers to commercial development it the lack of funding. A consultant supports that there is a need for large government undertaking for actual RE implementation to pay for feasibility studies and disseminating of research (Energy & Sustainability Engineer, personal communication, 25 March 2020). Overall, the ORE sector requires government and public support tools to reach large-scale implementation. Companies can accomplish the engineering design in an efficient and economical way, but need to have the capacity to rely on the supply chain for mass production, volume effect of the device.

5.3 Economic potential (SQ3)

5.3.1 Costs

Aquaculture

Catapult (2019) confirms that fuel costs for service vessels offshore are the second highest operational expenditure and O&M contributes to 20-25% of LCOE. Results show that diesel fuel is a high share of energy, in which case cost displacement would lead the argument for integrating ORE energy.

O&G

One of the largest costs in the O&G value chain is the building of as Austrade (n.d.) informs that building pipeline system to link offshore O&G to mainland is more than AU$4.5million per kilometer (km). To put into perspective, the Conoco Phillips project in Browse Basin (Annex 11, Table R) plans a 230 - km pipeline to a platform and 770 km pipeline to Darwin, which amounts to AU$1045 million and AU$3465 million, respectively. Then there is a West –East Gas pipeline project proposed by the government investing AU$5 billion to start in 2020, which is expected to cover a 2900km route – this amounts to over AU$13 billion (Annex 11, Table R). Considering the number of exploration projects anticipated, the subsequent investment of pipelines would be in the folds of billions of dollars. It is argued that part of that investment could be redirect toward installing ORE devices on service vessels used in offshore drilling. Besore (2010) writes that fuel consumption is the largest operational cost used in drilling and for diesel generators on oil rigs. IPIECA suggests that engines use 20-30 m^2 of diesel fuel per day (2013).

Ports

No specific costs related to energy are found online. Rather, interviews suggest that main costs incurred are for electricity own use and transport fuel.

5.3.2 Tidal and wave technology

The following paragraphs seek to provide detailed quantitative information relating to the economics of tidal and wave devices. The aim is to calculate an economic potential based on the literature source economic data, expert interviews, and technical potential discussed prior. Seanergy (2016) writes the installed and planned capacity for tidal and wave power globally. So far Australia makes up 31% of total installed capacity globally (Table 59). By the time of projected wave energy output, Australia makes up 1% of planned global capacity. At the time of writing, there is no specific data for Australia on installed or planned tidal energy resource capacity.

Table 59: Australian and Global ORE power output capacity currently installed and future planned capacity (Seanergy, 2016, p.6)

Australia		
Capacity [MW]	**Installed**	**Planned**
Wave	1.25	3
Global		
Capacity [MW]	**Installed**	**Planned**
Wave	4	411
Tidal Stream	8	139

A few literature sources exist and publish capital expenditure (CAPEX) and operating expenditure (OPEX) values (Table 60,61). CAPEX are expenses for future benefits, for example, buildings and machinery; OPEX are day to day costs, for example, leases, wages and office supplies (Cisco, 2018). The estimated commercial time phases and costs of technology vary, so it is important to note that the data can only be verified through in situ empirical experimentation.

Table 60: Calculated average of CAPEX, OPEX and LCOE for tidal and wave energy technology development status > TRL 6 (adapted from OES, 2015, p.6).

			Averaged costs from min and max values		
Energy	**Factor**	**Unit**	**1st project**	**2nd project**	**Commercial scale**
Wave	CAPEX	€/kW	9779	8363	5177
	OPEX	€/kW/year	283	265	199
	LCOE	€/MWh	-	389	261
Tidal	CAPEX	€/kW	8717	5752	3938

	OPEX	€/kW/year	584	301	217
	LCOE	€/MWh	-	301	181

Table 61: Calculated percentage decrease in CAPEX and OPEX for tidal and wave energy technology throughout the stages of development (adapted from OES, 2015, p.6) (Author's own).

% Cost reduction in technology development				
Energy	**Factor**	**1st-2nd**	**2nd-comm**	**1st-comm**
Wave	CAPEX	86%	62%	53%
	OPEX	94%	75%	70%
	LCOE		67%	
Tidal	CAPEX	66%	68%	45%
	OPEX	52%	72%	37%
	LCOE		60%	

Table 61 suggests that for wave energy the highest cost reduction is in the CAPEX and OPEX from the first project to the second project demonstration. When comparing the cost change from 1st array to commercialization for wave energy, the largest reduction is in operational costs (-70%), then in LCOE (-67%), then CAPEX (-53%). When comparing the cost change from 1st array to commercialization, for tidal technology, the largest reduction is in OPEX costs, followed by CAPEX from 2nd project co commercialization (-72%). Smaller cost reduction occurs in tidal technology for OPEX (37%) and CAPEX (45%) from the 1st project to commercialization compared with wave. This makes sense because tidal is more advanced in technical maturity than wave, so wave will undergo significant cost reduction as deployment projects increase in the near term. The change in LCOE for tidal technology from the 2nd project demonstration to commercialization scale is similar to that of wave, with a reduction by 60% and 67%, respectively. CAPEX values for tidal and wave energy from 1st project demonstration to commercialization decrease overall by approximately half with 45% and 53%, respectively, which matches with the percentage reduction costs calculated based on data published by Seanergy (2016).

The development status of the technology developer responses represented are based on tested technologies with TRL≥ 6 that are active in the sector at the time of writing. An exchange rate of €1.00 to USD1.13 was used. There are 9 stages representing the Technology Readiness Level of a device (Table 62).

Table 62: Technology readiness level past trial (level 4) stage (IMOS, 2019)

TRL	Description
5 "Verification"	Technology validated in relevant environment; Spatial and temporal sampling verified.
6 "Operational"	Technology demonstrated in relevant environment; Demonstrate system-wide use and availability.
7 "Fitness for purpose"	System prototype demonstration in operation environment; Satisfaction of multiple user needs.
8 "Mission qualified"	System complete and qualified; Fully scalable.
9 "Sustained"	Actual system proven in operational environment; Adequate sampling specifications.

Table 63: Capital and operational costs for wave and technology developers from 1st array project to commercial stage (Seanergy, 2016, p.13)

Energy	Factor	Unit	1st array	Commercial
Wave	CAPEX	k€/MW	6750	3675
	OPEX	€/MW/year	360	75
Tidal	CAPEX	k€/MW	7050	3450
	OPEX	€/MW/year	460	210

Table 63 shows an aggregated average of CAPEX and OPEX values from different literature sources, notably from OES (2015) and Carbon Trust (2015). When comparing to the OES specific data tables 65 & 66, Seanergy (2016) has a lower range of cost estimates, for the first array and commercial stage development. The lower costs in table 60 suggests a more optimistic scenario for prospect cost reduction in tidal and wave energy as the technology development stages progresses to a commercial scale.

Table 64: Calculated percentage decrease in capital and operational costs for tidal and wave energy technology from 1st array to commercial stage of development (adapted from Seanergy, 2016, p.13) (Author's own).

% Cost reduction in technology development		
Energy	**Factor**	**1st-comm**
Wave	CAPEX	46%
	OPEX	79%
Tidal	CAPEX	51%
	OPEX	54%

Tables 63 and 64 show that the largest cost reduction is seen in wave operational costs, which can be explained by multiple pilot projects that have been deployed globally in recent years (i.e. over 100). Additionally, OPEX for tidal is higher because most turbines are fully submerged or placed on the seabed, so installation costs are significant. There is an estimated halving of the costs expected for tidal CAPEX and OPEX from 1st array technology to commercial scale.

Over the past decade, there have been important advancements in tidal and wave energy development, though there are technical and financial barriers in up-scaling to hundred kW or MW-scale devices. There are high investments needed and technical barriers to upscale devices to hundred kW or MW-arrays. However, the trend suggests that with increased technology deployment CAPEX costs will begin to decline.

When looking at CAPEX and OPEX for tidal technology for 1st and array and commercial, both literature sources provide an economic value that matches very closely to one another (Table65). On the other hand, when looking at CAPEX and OPEX for wave technology for 1st array and commercial scale devices, both literature sources provide an economic value that differ more widely to one another (Table 66). It is important to note that Seanergy (2016) displays cost per MW of energy, which may explain a slightly lower cost range because a larger electricity output is taken into account.

Table 65: Comparison of CAPEX and OPEX per development stage for Tidal energy from two literature references (OES, 2015; Seanergy, 2016) (Author's own).

Development Stage	Literature	CAPEX (€/kW)	OPEX
Tidal – 1st array	OES, 2015	8717	584 €/kW/year
	Seanergy, 2016	7050	460 €/MW/year
Tidal – Commercial	OES	3938	217 €/kW/year
	Seanergy, 2016	3450	210 €/MW/year

Table 66: Comparison of CAPEX and OPEX per development stage for wave energy from two literature references (OES, 2015; Seanergy, 2016) (Author's own).

Development Stage	Literature	CAPEX (€/kW)	OPEX
Wave – 1st array	OES, 2015	9779	283 €/kW/year
	Seanergy, 2016	6750	360 €/MW/year
Wave – Commercial	OES	5177	199 €/kW/year
	Seanergy, 2016	3675	75 €/MW/year

From tables 65 and 66, OES (2015) shares a more reserved estimation of expected lowering of costs from 1st project array to the commercialization stage for both wave and tidal energy technology compared to data published by Seanergy (2015). In general, as the development stages of tidal and wave technologies progress, all costs (averaged) follow a decreasing trend, by a minimum of 50% and maximum of 94% from 1st project to commercial array scale.

The company representative at Sabella shares the following capital expenditure costs of capacity for tidal turbines:

- A demonstration project of 1 MW turbine: one unit is AU$12 million per MW.

- A pilot farm of 2-10 turbines of 1MW stands at AU$8 million per MW.
- A commercial scale is estimated at AU$5 million per MW.

The objective costs of LCOE for the horizon year 2025 stand at AU$250 per MWh.
(Commercial Development Engineer, personal communication, April 24, 2020).

The trend observed with scaling of devices based on the experience shared by Sabella suggests a decrease between 30%-40% per stage specifically with -34% from demonstration projects to multi-unit array deployment (2nd array) and -37.5% from 2nd array to commercial scale. The overall cost reduction from single unit demonstration project to commercial scale amounts to a 58.3% decrease, which matches closely with estimates provided by the Seanergy (2016) for tidal stream power (i.e. -51% from 1st array to commercial). The LCOE suggested by the company Sabella matches closely with the LCOE at commercial scale for tidal technology estimated by OES (Table 60) which amounts to about AU$300 (i.e. with a currency rate of AU$1.65 per €1.00).

Summary

ORE technology has reached a successful deployment stage but financial and technical operation barriers remain (Dept. Industry, 2014). The price of solar PV and wind have experience a continuous fall of price over time, where the same trend can happen for ORE. The majority of existing grid-connected ORE capacity is placed in the UK with a few prototypes present in Europe, North America and Asia. After installation, new research concerns involve optimizing the performance and longetivity of a turbine and assess the energy generation potential of target site (AMC, 2017). The Ocean Energy Systems (OES) organisation highlights that, "A key challenge in predicting commercial opening costs in wave and tidal sectors is acquiring meaningful data … [as] very few data points are available from actual deployments and all existing data points come from pilot and demonstration projects, not larger-scale farms (2015, p.13). Similarly, The IRENA writes that the reason for limited economic data available for tidal and wave energy is because the costs are site specific (2014). In addition, each technology can present its own unique challenges and impact the stage of development (OES, 2015). Strategies for a positive economic potential are to generate more energy per unit of CAPEX and have improved design to increase energy capture. Reductions in structure, O&M and improvement in energy yield will help reduce overall costs of energy and are marked as high priority areas for R&D.

5.4 Political Landscape (SQ4)

Renewable energy innovation is defined according to: “Accelerating research for a low carbon future” (IRENA, 2017, p.1). Development considers the advances in the technology readiness level (TRL) of tidal turbine and wave energy converter devices. Innovation plays an important role for the decarbonisation of marine industrial sectors. In Australia, transforming the energy mix is a slow process, because of limited climate change adaptation and mitigation as well as a lack of ambitious renewable energy targets (Table 4). Maltabarow (2017) confirms that the main barrier to transition from coal in Australia is, “the current lack of a policy framework that aligns environmental and energy goals in a way to be sufficiently stable and that facilitates the investment required.” The Carbon Trust (2011) writes that cost of energy can be reduced through innovation (p.28)

In terms of ORE in Australia, the major upcoming was the launch of the BE CRC initiative at the end of the year 2019. The FRDC (2020) shares that scaling up low emission technology is necessary to reach (net zero) targets. There is a competitive advantage when renewable energy systems integrate intermittent sources with storage and new renewable installation where it actually becomes a more affordable measure for reliable electricity generation (UNSW, 2019). There is a need for comprehensive and credible climate policies to direct investments for sustainable energy market interventions. Maltabarow (2017) suggests that delivering significant amounts of new energy supply can improve electricity supply reliability and increase the affordability because the added share of RE can reduce wholesale costs. The PWC (2019) writes that Australia could see strong economic and emissions benefits, with over AU$10 billion to GDP by moving to a renewable power system with more than 60% in 2040.

An interview with the consultant – government and policy specialist member of AOEG helps inform the legislative situation in Australia (Annex 9). The goal of the conversation was to gain insight on the role of regulation and legislation in the development ocean energy, the progress of renewable energy, and the activity of marine industries from a government’s perspective. The interviewee shares that within the marine sector there is no relationship between the government and the industry. An issue is that the regulatory regime is complex since each state and territory holds its own regulatory framework and authorities. Another difficulty is that there are various levels of legislation that lengthen the process to acquire permits for specific activities, such as commissioning an ORE device. The FAO confirms that state and territory governments are responsible for resource management within a state or territory (p.4). The interviewee suggests that to advance in the deployment project stages to commercialization, the industry body should be the one to take forward legislation. Lastly, constructing a benchmark study on the length of time to install a device in the water, from approval to agency interaction could help in creating a sound risk approach for device deployment.

(Government & policy specialist, personal communication, 11 February 2020).

The following paragraphs seek to describe the experience and situation of each sector relating to Australia’s political framework as well as opportunities for innovation.

1) Aquaculture

There is a lack of specific regulation on emission production limits or abatement strategies in Aquaculture; However, there are very strict regulations for the salmon industry in Australia with specific legislation in each state or on production of species.
There are numerous national organizations that base efforts for sustainability in Australia. The Department of Agriculture, Fisheries and Forestry (DAFF) holds executive responsibility for aquaculture in Australia and the Primary Industries Ministerial Council is in charge of with issues on a national level that deal with sustainable production objectives (FAO, n.d.). The DAFF states that The Fisheries Research and Development Corporation (FRCD) manages and has invested in 10 strategic R&D programs surrounding natural resource sustainability and industry development.

The government is focusing on enhancing sector growth and sustainable competitive advantages The Australian Fisheries Management Authority (AFMA) is a management overhead that administers environment assessments, research needs, and provides services for fish farmers (AFMA, 2019). The Commonwealth Fisheries Association (CFA) takes a leadership role to secure the responsibilities of commercial fishing industries that enhances environmental sustainability, long term improvement in efficiency and continued profitability (AFMA, 2019).

Based on the literature it seems emphasis is on integrating an ecological sustainable framework for business opportunities to secure industry growth and global market opportunities. Ecology is linked more closely to species biodiversity and conservation, than on an energy system. There has been a growth of sustainability certification labels. Key subject areas forming the basis for sustainability reinforcements include monitoring the status of key species, ensuring the maintenance of stocks, and supervising that commercial activities follow recommended guidelines.

On a positive note, there are incentives and R&D investments into new ways for growing salmon, especially for offshore farming (Toner, 2002). Aquaculture is on the forefront with regards to innovation, as it is the priority of several research areas of the BE CRC. The objective is to “support existing industries [for a] move offshore and develop, test and evaluate innovative product, production and processing systems for a range of seafood species” (BE CRC, 2019c). One focus area is to push for commercialization opportunities with innovative aquaculture system design. Companies are also playing their part in enabling industry growth. For example, at Huon, the founders know there are benefits from an investor’s point of view for a company to have set goals and sustainability strategy is represented at an executive level, well integrated within the company’s mindset (2020a).

To conclude, the political context for aquaculture and opportunities to integrate ORE power sources in the industry is promising for the horizon 2030. The leadership role of the BE CRC, the established environmental legislation and the active participation of multiple interdisciplinary stakeholders are notable characteristics that are advancing market development and opportunities within the aquaculture industry.

2) O&G

The legislative overview in the O&G industry mostly surrounds carbon emission activity. The majority of companies report emissions under the NGER Act 2007. The National Greenhouse and Energy Reporting scheme is a national framework for disseminating company information on GHG emissions, energy consumption, and energy production. The objective is to inform government policy and help meet the country's international reporting obligations (CER, 2019). There is an integrated theoretical carbon price in the decision making and models. There is a lack of government restrictions, for example companies can adjust the baseline of emissions upwards. CSIRO Futures (2017) shares that, "innovation in the oil and gas sectors is difficult, with uptake of new technology […] being relatively low" where there is the need to overcome the low levels of collaboration across firms to increase opportunity for innovation and commercialization (p.43).

The O&G industry has moved forward its production value chain to meet global demand of energy and hydrocarbon derived products. Given the industry is supply oriented, resource efficiency and product output are regularly considered for improvement, mostly from an economic perspective. In a survey, 73% respondents of oil and gas industries confirm the will decarbonize only if it makes financial sense for them (DNV, 2020a). Competitive pressure and the push to decarbonize hydrocarbon production operations encourages O&G industries to transition toward low carbon sources, and this competition can be stirred further in the short-term (e.g. 2025) by regulations and incentives.

The interviewee from the anonymous company shares it is essential for the government to provide support or a subsidy in order to incentivize companies to adopt emerging renewable energy technologies, such as ORE devices in this case (Corporate development manager, personal communication, June 12, 2020). If action is taken by O&G companies to shape business cases that propose sustainability objectives, it would prove the active effort on behalf of companies to the government. Proactivity by O&G stakeholders could help start constructive conversations with legislators and policy makers and options for financial support. The economy is currently engrained in seeing the benefits of for O&G exploration and drilling projects, but a new perspective on financial opportunities for integrating a larger share of renewable energy, and specifically ocean sources is needed. Efforts are beginning with the BE CRC research program focusing on offshore renewable energy systems and sustainable offshore development; However, the anchored fossil fuel energy sources of the O&G continue to be supported by investments as discussed earlier in the research. Economic benefits need to be reassessed to redirect financial opportunities toward ORE and a SET, for which the O&G sector plays an indisputable part. Renewable energy schemes and support mechanisms exist and Europe can serve as a leading example.

The European Commission highlights that Energy markets alone cannot deliver the desired level of renewables in the EU, meaning that [carefully designed] national support schemes may be needed to spur increased investment in renewable energy (EC, 2020). There is also the EU ETS to drive the energy market production efficiently and cost effectively. Temporal goals such as setting targets by 2030 then by 2050, help in "maximising competition and minimising the costs of developing renewable energy" as it allows the time for new technologies, infrastructure and materials to develop in time (EC, 2020, p.8). This strategy can be applied in deploying ORE in Australia over the next few years by increments of the suggested potential power capacity discussed by developers and calculated potential output based on technical and economic factors. The CISOR confirms that long-term progress in sustainability is possible through collaboration across the O&G sector as well as with multidisciplinary research and science (2017).

3) Ports

The leading organisation is Ports Australia (PA) which acts as the voice for Ports has made efforts to contribute to making positive environmental impact and move towards renewable energy (2019). Climate change will pose challenges to the operations of ports and their infrastructure in upcoming years. Ports can create value by enabling opportunities for collaboration, comply with regulatory requirements, and build resilience to difficult environment conditions (Flinders Port Holdings, 2020).

In Australia, several ports are (state) government owned which means information and practices are bounded by government decision making. For example, the PoG, a GOC, relies on state and national legislation to carry out commercial activities (Sustainability specialist, personal communication, 30 January 2020). In the case for adopting alternative energies, the potential investment in renewables is bounded by QL policy. PA organises workshops and collaborative platforms in order to bring together port experts, government and industry to discuss emerging issues and potential approaches for driving long term prosperity. Then, PA may hold leverage in pushing policy works to improve the energy mix and system in the sector (2020).

The government needs to recognize the considerable engagement made by ports, as data suggests from the literature and interviews, in improving activity development while considering sustainability commitments. Actually, this year Port Australia published an extensive "Sustainability Strategy Development Guide" with in-depth methods for building an adequate sustainability strategy and focus areas such as supply chain efficiency, equipment efficiency, industry partners and stakeholder engagement. Ports are implicated in sustainability to varying degrees, ranging from having a separate sustainability branch team to not having a written sustainability report. Measures include lighting efficiency, emission reduction and carbon positivity goals. Ports are taking into account GHG performance and following SDGs for guidance, and have been considering GHG emission mitigation much more than in the past. The source of information online shows that there is an increase of sustainability planning projects and reports being published. As such, the government can equally contribute toward facilitating ORE projects and achieving long term sustainability for an important placeholder sector in Australia's economy.

4) Technology Developers

When government assist in R&D and support demonstration project, they can positively impact the rate at which the technology progresses (Dept. Industry, 2014). The CSIRO confirms that there is no unified approach to ocean energy and that a carbon price as well as policy stability will be essentially in Australia for ORE energy uptake (Behrens et al., 2012). Through interviews, technology developers commonly share that there is an urgency to achieve cost-effective technology given the high risk, difficult environment and capacity potential of other available electricity supply competitors. European companies are global leaders in ocean energy, holding 44% of wave energy patents and 66% of tidal energy patents (OES, 2020). Since 2016, the EU has guidelines for authorities and power producers to work in a new power market where -scale ocean energy projects have priority access to the power grid and in dispatch. The most common financial instruments for market integration of renewables are feed-in tariffs, tax exemptions, quota obligations and investment aid (EC, 2020, p.5).

In summary, the government will be an important enabler for rapid uptake of ORE in Australia and within the maritime sectors investigated in this research. The opinions and facts of each sector analysed can inform government policy makers with relevant and precise data. Collaboration with Europe is in the early stages, but with commitment from the Australian government, new opportunities for collaboration and market growth may become feasible and valuable in decarbonisation pathway toward the horizon 2030 and beyond.

6. Discussion

The research identified the barriers, risks, opportunities and perceptions for tidal and wave technology in Australia. Findings on the energy use, energy mix and emission per industrial company in the Blue Economy was used to fill the gaps of knowledge on ocean renewable energy (ORE) deployment stage and progress toward reaching market. The literature points to the advantages of tidal and wave energy as a highly predictable on a daily basis, with a narrow range of variability compared with other mature renewable energy sources, such as wind and solar, and high percentage availability (85%-95%) of the resource. The research shows that the role of the BE is paramount for stimulating multidisciplinary expertise for the commercial development and design optimization of tidal turbine and wave technology. Results suggest the need for further climate change policies that can support emerging renewable sources such as tidal turbines and wave energy converters (WECs). There is a need for collaboration between legislative decision makers and industry stakeholders to reduce the time barriers for acquiring permits and environmental approvals needed for device testing.

The research provides novel numerical findings on the offshore energy system and sustainability management of marine sectors at the company level. The data allows for current representations of energy demand and power supply per source type in Australia compared which are lacking in the current literature available. For example, literature on aquaculture species production is mostly found for Canada, the United States and European countries. Sustainability reports for the O&G sector are mostly under the form of environmental management activities and financial reporting of energy production per company, so no data is specific to percentage of energy own use. Significant information related to trade is publicly available for the ports sector, specifically vessel throughput per year. However, it is difficult to find energy demand related data for the port's utilities and local activities. As such, this research was able to contribute to the larger scientific body of knowledge by establishing a preliminary database. The research can be improved by spending more time to inquire each sector with precise questions on operations. A larger scoping of tidal and wave technology developers in Australia would improve findings for calculating power capacity potential of ORE while considering the trend in reduction in capital and operational costs examined. This way a unique market value potential for Australia from 2020 until 2030 can be estimated per source of energy use in offshore industries of the BE.

Impact of Research

The multi-disciplinary nature of the research is an important aspect because the information is relevant to a diverse set of stakeholders. The data collected on the energy system, sustainability management, and carbon footprint of the industries can be disseminate to ocean energy technology developer companies, to consultancies working in the field of renewable energy and resource management, and to government representatives. The data was analysed and summarised in a simple manner to make sure it is understandable and is applicable to cross-cutting disciplines. The different expertise and opinions shared in interviews can help spread knowledge and improve communication between technology developers, industries, and policy makers. For example, developers can understand the energy needs of marine sectors, then identify design improvements and ask for government support for commercial success. Industries can have a reduced risk perception of the technology by having a better understanding of the technical advancements of ORE that could meet power requirements to run operations.
With the support of the aforementioned research institutes and with additional scoping studies, the data can inform decision makers for policies and legislation surrounding the uptake of renewable energy, with a focus on ocean energy sources.

Energy consumption values and emission volumes per industry is a preliminary basis that can be used to inform current research on offshore renewable energy systems and decarbonisation pathways for Australia carried out by the Commonwealth Scientific and Industrial Research Organization (CSIRO) in collaboration with the Blue Economy Cooperative Research Center (BE CRC), the Australian Ocean Energy Group (AOEG) and Climate KIC. The keen interest from multiple organisations and institutions, both locally and abroad allowed to provide an overview of economic interests and potential implementation barriers. Considering several stakeholders of the BE are investigating pathways for low-carbon energy sources, the research helps to understand the potential advantages and weaknesses of adopting ocean renewable energy (ORE).

In the case that more companies are represented per sector, and further data collection is carried out, the overall impact for emission abatement by relying on ocean sources will prove to be significant for Australia and contribute toward emission reduction goals set by the Paris Agreement. Specifically, the aquaculture companies researched are three out of nine dominant Australian aquaculture companies on the market with Tassal holding the largest market share (41%), followed by Huon (25%). In the case that ORE uptake is aggregated for all aquaculture companies, the potential can be estimated to approximately 35% higher than the presented results. Further research would be needed to know the share of energy demand of the remaining six companies attributable to electricity use.

There is a total of 48 ports throughout Australia and five ports located across four states, Western Australia, South Australia, Northern Australia and Queensland, were researched. In the case that ORE uptake is aggregated for the majority (70%) of Australian ports, because of tidal or wave resource limitations in certain states and territories identified by the Wave Energy Atlas research by the CSIRO, the calculated ORE potential estimated is still likely to be higher than the presented results. Further investigation on all port infrastructure, tidal current speed, incident wave energy and energy mix system of all Australian is needed to find a precise percentage for tidal and or wave energy potential power capacity.

There are 30 major O&G companies in Australia assumed to have part or all of exploration, well drilling and production activities taking place offshore. The findings of the research used to calculate ORE potential power projection and emission abatement represent three companies in the sector. In this case, by taking into account company size and economic production value, ORE potential is likely to be in the fold of hundreds of Megawatts rather than kilowatts; a similar extrapolation for emission abatement can be assumed, where million tonnes carbon dioxide (Mt CO2) can be displaced rather than kilotonnes (kt) CO_2.

The energy consumption was found to be highest for the O&G sector, followed by the aquaculture industry, and then ports. Considering data is based on a company's activities in one year, results may be an overestimation or underestimation. Trends suggest an expected growth in activity across all marine sectors. Accordingly, emission output as well as ORE uptake power capacity potential will rise in upcoming years for Aquaculture, O&G and ports. Then the potential emission abatement, will be notable from installing tidal and wave device technology to meet a part of energy, specifically electricity and diesel needs of industries.

Aquaculture

Tassal group production is largest followed by Huon Aquaculture, then Petuna. Correspondingly, results show that Tassal has the highest recorded energy demand followed by Huon and Petuna, in 2019 and 2020. The energy demand for Huon and Petuna presented is likely an over estimation because the energy demand ratio used as a baseline pertains to Tassal, an aquaculture company that is leading larger operations than Huon and Petuna. There is available literature with detailed energy ratios and process operations analysis for global and European based aquaculture, but such detailed quantitative data was limited for Aquaculture in Australia. To maintain a validity and accuracy of results two main sources were used to compare our results. Information published by the leading researcher of the offshore renewable energy program in the BE CRC was used as a baseline to calculate energy demand and subsequently, ORE technical potential for each of the three aquaculture companies because it is the most recent data on aquaculture activities in the BE. To estimate the ORE technical potential for aquaculture, data for the energy mix of Tassal in 2017 was used as a reference. Specifically, 36% of electricity use was estimated to be the feasible mid-range value for displacing fossil fuel based electricity with a rate of 22% annual growth in ORE installation in Aquaculture until 2030. The ORE potential proves to correlate with the positive trend in energy consumption, where Tassal has the largest cumulated ORE power potential reaching close to 15 MW in 2030, followed by Huon and Petuna, reaching approximately, 12 MW and 3 MW by the same year. The estimated overall MW capacity for electricity demand in Aquaculture marks a high market potential and important contribution from the sector in implementing ocean resource in Australia. The values calculated may be an overestimation since a linear growth trend of installation of devices is estimated; However, anticipated cost regression of tidal turbines and wave energy converters (WECs) that will occur through future deployments and through reaching market commercialization within the next five years confirmed by developers themselves, a high ORE power output potential is feasible.

O&G

Of the O&G industries investigated, Woodside ranks as the highest energy consumer, having an energy demand, in 2018, that is more than two times that of Conoco and over 200 times more than the anonymous company. All companies have minimal records and details on the company's overall energy demand, energy demand per operation and energy mix components. Similarly, up to date data records are limited and not easily accessible for GHG emissions. Of the companies investigated, data is sporadically spread over different time frames and various sources of GHG emission sources. Most of the O&G companies have equity in exploration, developing or producing projects and a significant share of operations in other countries, so data pertaining to Australia is minimal. For example, some companies report direct and, or indirect scope 1 and 2 emissions, other companies report total emissions; One company includes emission intensity, and another displays scope 3 emissions. As such, the data chosen for analysis is that of three companies that reported emissions in 2018, where evidently Woodside holds the highest scope 1 emissions. Conoco shows more than two times the volume of emissions for both the anonymous company and Arrow Energy. To estimate a technical potential for power generation input from ocean sources Woodside's energy mix data was used as the reference to extrapolate value for the remaining companies' electricity use. The potential ORE power is relatively small compared to overall energy consumption sourced from fossil fuels, considering the largest cumulative ORE power potential is 4465 kW in 2030 followed by 2046 kW and 22 kW in the same year for Woodside, Conoco and top 5 ASX companies, respectively. These values align well with the context of O&G offshore fossil fuel dependence and opinions shared that companies are more likely to choose from solar renewable first, before considering tidal and wave devices. The likelihood of the O&G sector to adopt ORE in the next decade is low because of the uncertainty of ORE devices technology to meet the constant, high energy requirements to run operations, and trade activity volume. Then, the overall market potential for the O&G sector is unlikely, unless government financial support schemes and stringent legislation on emission reduction targets are enacted in the next two years in Australia.

Ports

Of the Australian ports investigated, calculated results show that the Port of Gladstone has the highest recorded energy demand in 2019, followed by the Port of Brisbane, then the Port of Esperance and finally, the Port of Townsville. The trend in energy consumption related to the size as well as the incoming and outgoing trade activity of each port. For calculations, the energy mix of Port Brisbane published in the sustainability report was referenced to extrapolate values for the remaining three out of four ports' missing either total energy or electricity values. The largest cumulative ORE power potential is 1509 kW in 2030 followed by 458 kW, 238 kW, and 38kW in the same year for the ports of Brisbane, Esperance, Gladstone and Townsville respectively. There is a high market potential for ORE ports evident with past tidal turbine demonstration projects and recent involvement of multiple institutions and companies dedicating research to the sector.

A possibility to contribute to increased volume production of tidal turbines or wave energy converters is to an in-depth study of available and suitable infrastructure of Australian ports for deploying and testing devices. The findings can complement the available wave energy atlas database published by the CSIRO with specific information on wave energy potential around Australia.

Economic outlook

The perspective of consultancies and technology developers along with literature sources are used to inform the economic potential of ocean sources for industrial marine sectors in the BE. Data suggests that current costs of ORE are in the folds of millions of dollars for demonstration projects but have promising outlook with least 50% and up to 70% cost reduction as the devices reach commercial stage. The literature converges to a reduction in 51% of capital costs for tidal and 46% of capital costs for wave from first array pilot tests to first commercial scale deployments. Operational costs are expected to undergo a higher cost reduction per technology type, notably for wave reducing by over 75% from first array pilot tests to first commercial scale deployments, and tidal energy that is expected to reach 54% reduction in operation costs as the technology progresses to toward market viability. Data for the levelised cost of electricity (LCOE) of each technology is shown from second phased demonstration, or multi-array test development, to commercial scale, where both tidal and wave fall in a range of 60-70% cost reduction. While the LCOE for solar and wind in Australia make more commercial sense than ORE at present, government supported financial mechanism can play a role to alleviate the cost differential and bring ORE onto the market. It is difficult to make a calculation of operational costs for both tidal and wave energy because the two main literature sources referenced for quantitative data show a price per unit of electricity where the electricity output differs by 1000 folds (i.e. €/kW vs. €/MW). Additionally, making a projected price degression for capital expenditure costs for ORE is limited because the technology has not reached a convergence of design, so assumptions would make the results highly uncertain and of low accuracy. For a project cost calculation of tidal and wave energy, it would be beneficial to carry out an in depth economic analysis pertaining to all Australian companies as well as international companies with project developments in Australia. This way a large sampling pool and numerical values per type of technology and design can be accumulated to form a robust database. The economic potential is currently low for the marine sectors investigated, since the price of ORE does not make economic sense when compared to the affordability of other renewable sources. However, the highly intermittent characteristic of solar and wind sources of energy is an issue that can be resolved by integrating a share of ocean energy, which holds over 85% and up to 95% availability.

Ocean resource is vast, infinitely available and can be extracted as a reliable and predictable source of energy meanwhile innovation in device design progresses and the technology readiness reaches a higher level. General opinion from technology developers is that device testing and deployment are well advanced and hold a good connection to target customer sectors since companies have undergone multiple demonstration projects over several years. Companies are eager to reach commercial scale, yet a financial push from the government is paramount to enable volume production and reduction of costs. Grid connectivity needs to be improved to integrate ORE sources as a beneficial input with intermittent, competitive renewable sources such as wind and solar. There is value in developing an integrated energy system to work toward sustainability targets, and smooth out market demand as well as future costs of electricity in marine sectors of Australia that have an important current and future economic contribution to the overall economy.

Overall there is a market potential for ORE in Australia throughout all industries that can hold impact for transitioning to a more sustainable energy system provided there is serious government support, substantial financial mechanisms for end users and technology developers, and increased further research and development. The highest ranked potential is found for aquaculture and ports, and a low potential is found for the O&G sector. There is unanimous consent that collaboration and interdisciplinary exchange of expertise across sectors is key to motivate change for the future of the energy and carbon system of Australia's BE.

Limitations

The industrial sectors in Australia evaluated for energy consumption, carbon emissions and economic factors had significant limitations on available quantitative data. This resulted in a research that was weighted toward a greater qualitative accuracy whereas quantitative led results had been anticipated in the original research proposal.

For GHG emission estimates the client portal with information on the national greenhouse emission reporting scheme proved to be limited in detail. This reoriented the research to focus on the energy system of industries and potential for carbon abatement, rather than seeking to illustrate the carbon footprint of each industry. It is suggested that the CER platform is more easily available to the public with sector specific portfolio of data that can contribute to research, analysis and interpretation. This way a better perspective could be obtained and narrowed to the marine industries of Australia. For now, energy and emission trends aggregate industries so it is not possible to depict values specific to marine industries. With further development and specificity of emission abatement calculations, the data could contribute to the CER platform.

For technical potential calculations of ORE power capacity and emission abatement, the results are short of representing the entire marine sector, because only a few of the company or ports case studies are included. Energy consumption data was not homogenous in terms of units or timeframe per sector and per energy source type. Data was not provided by personal communication for several individual sector entities. In the case that data was shared, there was a lack of definition on the categories reported for energy use, electricity consumption and emissions even though clarification was inquired from the interview participants, but was unfortunately not met. The technical potential estimated is a simplified, preliminary calculation that needs to be developed further by including additional market factors (e.g. price fluctuation, electricity demand, imports, exports) that may impact the deployment potential of the technologies in Australia in upcoming years.

Assumptions and simplifications of calculations were made for quantitative analysis, where improved statistics and data samples would be beneficial for better accuracy of results. The lack of numerical data pertaining to ORE development in Australia restricted the capacity to carry out precise calculations to evaluate the market potential quantitatively. Rather the market potential is expressed in terms of low, medium or high potential for the sectors investigated in this research.

The methodology of this research would benefit from a more clearly defined organization of data collection per subject category investigated (i.e. technical, economic, political) which was not achieved because of difficulty in obtaining interviews in the time frame that was planned.

The lack of recent climate change adaptation and mitigation policy in Australia complicated the validity in building scenarios for alternative sources of energy conversion in Australia in the decade and up to 2040 and 2050. It may be beneficial to propose national climate change scenarios that can be based on European Union's renewable energy projections. This highlights the need for improved involvement and sustainability strategy on behalf of the government. It was evident in conversations that the country is not a first mover in adopting renewable energy targets which allows industries to keep business as usual.

Further Research

Further analysis is needed to compare the energy intensity of each sector to draw a precise energy demand projection and potential for displacing fossil fuel energy use with ocean sources. Further research on energy efficiency within each sector's operations and processes can further inform the energy pathway for marine industrial sectors until 2030.

Our findings aim to contribute directly to the current research carried out by the BE CRC in collaboration with Aquaculture companies, renewable energy system engineers, offshore platforms, academic institutions and researchers. Once the information is published, it would be interesting to compare quantitative and qualitative data to fulfill the remaining gaps of knowledge.

There are different systems used in aquaculture for fish cultivation and production. Having detailed data records on the energy intensity of each operational mechanisms would help to identify the where tidal or wave energy could have most impact in displacing those energy needs. Further research into the O&G sector can be accompanied by the Oil and Gas Roadmap published by the CSIRO, which identified four priority areas to have a better impact on future energy and resources. In the case of the O&G sector, questioning the volume of energy production for market and working alongside an engineer could help in relating the impact on energy consumption. In the port sectors, it is necessary to collect tidal data and expand the sampling of ports to several states of Australia. Daily tidal ebb and flow charts available per port location are needed to calculate a tidal power potential which would be used as a precise input for tidal turbine energy uptake in ports. Further research is needed to explore which ports are best suited for tidal turbines or WECS, or whether both ORE technologies are evenly distributed. Another area for further research is to look into which infrastructure is more suitable for an ocean energy device over another (for example port landings versus offshore oil and rig platforms) and how this will impact the rate of deployment and ultimately future competitive advantage of ocean technologies within Australian marine sectors.

There is potential to extend our case study of marine sectors to also include ocean observation and coastal communities. Multiple instruments are used in ocean monitoring that rely on batteries for which ORE could serve as a power source. In remote island areas, communities incur high costs for fuel because of a reliance on diesel generators for electricity. A case for ocean energy installation and cost displacement in off-grid areas would complement the research findings.

7. Conclusion

The original idea that marine industries of Australia are fossil fuel dependent industries for sourcing energy in operations and production value chain is confirmed from data collection and analysis of three selected sectors representing the Blue Economy, specifically Aquaculture, Oil and Gas, and Ports. The hypothesis that ocean resource, specifically tidal stream and wave energy, can serve as a meaningful energy input and contribute to the energy mix of marine industries was proven while taking into account a period of several years to allow for the technology to mature, to overcome present financial barriers, and reach a commercial scale and profitable market margin.

This research provides a qualitative and quantitative information on the energy system of three marine industrial sectors within Australia's BE exclusive economic zone. A case study approach sets the technical, economic, and political basis for introducing tidal stream and energy wave conversion devices to fossil fuel dependent maritime industries.

The activity surrounding ocean sourced based energy conversion is on the forefront of innovation, research and development opportunities for global climate change mitigation and adaptation. The market potential for reducing reliance on conventional carbon-based fossil energy transformation with ocean tidal stream and wave energy is truly promising in the Australian context and can help achieve emission reduction commitments by 2030. The advancements in ocean energy is moving forward technology to be fully scalable and sustained in its operational environment. Several European technology developer companies have formed a commercial network and performed demonstration projects in Australia. There are more and more partnerships forming to build the business case for ocean energy in offshore marine-related activities. Australian companies are also securing contracts to deploy tidal turbine and energy wave converter devices within niche markets. The growing global and Australian customer segment is moving the technology forward along both the learning and cost curve. As a renewable resource, ocean power is a source of energy that proves beneficial within an integrated renewable energy system, that is by combining mature renewables (e.g. solar and wind) and battery storage. Promoting ORE as an energy resource opportunity does not mean excluding all other forms of energy since benefits and drawbacks are present in each resource context. The idea is that barriers can be overcome through multidisciplinary expertise recognizing the advantages of each technology and work toward a sustainable energy transition, achieving climate goals.

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Interview References

Aquaculture
Huon: (Environmental Compliance and development manager on May 5, 2020)
Petuna: N/A
Tassal: N/A

O&G
Arrow energy: N/A
A top 5 ASX: (Corporate development manager, personal communication, June 12, 2020).
Carnarvon: (Energy & resources Executive Director, personal communication, June 4, 2020)
Conoco Phillips: N/A
Woodside: (Senior petroleum engineer, personal communication, May 2, 2020).

Ports
PB: (HSE manager, personal communication, May 15, 2020).
PE: (Envr. manager & envr. advisory, personal communication, May 12, 2020).
PI: (Envr. manager, personal communication, April 4, 2020).
PoG: (Sust. specialist, personal communication, January 30, 2020).
PT: (Manager strategy & sust., personal communication, April 2, 2020).

Tech Dev
Bombora: (Commercial Manager, personal communication, May 1, 2020).
Carnegie: N/A
MAKO: (CEO, personal communication, April 22, 2020).
Sabella: (Commercial Development Engineer, personal communication, April 24, 2020).
Wave Swell: (Commercial Manager, personal communication, May 1, 2020).

Industries
ATTERIS: (Asset Lifecycle Manager, personal communication, 25 March 2020)
NERA: (General manager innovation and strategy, personal communication, 19 March 2020)
ORE Catapult: (Analysis & Insights and Senior Mng. Researcher, personal communication, 18 March, 2020)
Pitt&Sherry: (Energy & Sustainability Engineer, personal communication, 25 March 2020)

9. Annexes

Annex 1: Description of case study Aquaculture companies

1. Huon

Huon Aquaculture was founded in 1986 by Peter and Frances Bender with a mission of sustainable farming and ethical business approaches (2019). It is a well-respected Tasmanian brand that sets priority on the welfare and safety of fish. The company strategy works in increasing transparency on its operations and carbon footprint to achieve sustainable practices (Huon, 2020a). Huon publicly delivers information and seeks communication to receive feedback that can help throughout their facilities and farming locations. The three main marine regions for production are the d'entrecasteaux channel, Macquarie Harbor and Bruny Island in Storm Bay (Figure A).

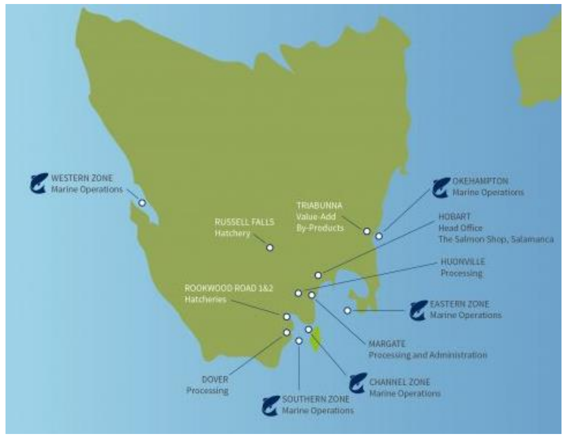
Figure A: Huon's range of operations areas map. *A-E,H, & I are hatcheries, F &G are facilities, and J is a nursery* (2020b).

2. Tassal

Tassal group is located in Tasmania and has been operating for nearly 30 years. The company operates three freshwater nurseries, four marine farming zones and five processing facilities (Tassal, 2020). Tassal takes leadership in transparent environmental reporting and seeks ways to tackle sustainability issues, notably by creating a sustainability dashboard with information accessible to the public. Tassal has taken responsibility in the transition to high energy resource potential offshore farming through their collaboration with the BE-CRC.

The company shares in its sustainability report the focus to align with the UN SDGs, notably the vision for eco-aquaculture through integrated multi-trophic farming. Multi-trophic aquaculture is a strategy to reduce ecological effects by recapturing the nutrients and by-products usually seen as excess and using these as an input source to cultivate the fed species (Choppin, 2010, p.195). This method increases sustainability because the externalities are recirculated into the production system value chain.

Figure B: Tassal marine operations and processing map (Tassal, 2020).



3. Petuna

Petuna was originally a fishing company that has diversified into aquaculture since 1990. The Tasmanian company holds outstanding recognition for product sustainability in Australia (Petuna, 2020). Petuna is committed to sustainable growth and production of high quality seafood. The company is expanding its operations because of increased market demand, allow to fulfil the 5-year growth strategy and aim to double production by 2030 (2020a). There is a hatchery in Cressy (Great Lake Central Plateau, TAS), marine farm sites in Macquarie Harbour and Rowella, and a processing facility in Devon Port (2020a).

Annex 2: Description of case study O&G Companies

1. Arrow Energy

Arrow Energy is an onshore plant that explores gas fields, produces and sell Coal Seam Gas (CSG) and generates electricity (2020a). The company is located in Queensland with resource supplies in two main areas: the Bowen Basin and Surat Basin (Arrow Energy, 2020). The company has close to 750 employees and has an estimated annual revenue of AU$183 million per year (Growjo, 2019). In 2017, Arrow signed a 27-year gas sales agreement to commercialise its gas reserves in a joint venture with Shell (2020b). The business has right of up to 600 MW of generating capacity from the three gas-fired power stations and produces an estimated equivalent to 40% of QL's domestic gas demand (Arrow, 2020a). According to the website, the company values the environment and seeks to meet domestic and international demand through cleaner energy production.

2. A Top 5 ASX O&G Company

The company representative required anonymity. The company is a producer of natural gas and is recognized as Australia's premier multi-basin upstream oil company with operational sites located in SA, VIC and WA (2020a). The company has close to 600 employees with an estimated annural revenue of $143.1 million per year (Growjo, 2019b). The company holds joint ventures and exploration tenements in several basins and supplies an estimated 15% of domestic east coast gas demand (Table A) (2019). The company is constructing additional production hubs, notably a facility with capacity of 10 TJ per day gas production (XXX, 2019). While the focus of this research is on offshore O&G, this company was chosen to gain insight on the relative scale of energy use for O&G operations.

Table A: A Top 5 ASX company production operations in Australia and New Zealand (XXX Ltd, 2020b).

Operation basins	Location	Project Description
Bass Basin	VIC	Operating partner, joint venture
Bonaparte Basin	WA	Exploration tenements
Canterbury Basin	NZ	Exploration tenements
Carnarvon Basin	WA	21% non-operating interest
Cooper Basins	SA	Joint venture partnership
Otway Basin	SA	Undertaking natural gas program
Otway Basin	VIC	Undertaking natural gas program
Perth Basin	WA	Joint venture operations
Taranaki	NZ	Joint venture interests

3. Carnarvon Petroleum Limited

Carnarvon Petroleum is a large operating, exploration company in Australia with several joint operations. Some of the largest oil fields were discovered in Western Australia's North-West Shelf (2017). Carnarvon has between 30-50 employees and an estimated revenue of $7 million per year (ZoomInfo, 2020). The company has raised close to AU$47,500,000 and invested AU$38,000,00 for exploration activities and asses in relation to drilling wells in some of the following project areas (Carnarvon, 2019, p.22):

1. Dorado Liquids and Roc Gas
2. Buffalo Oil field
3. Pheonix Project
4. Labyrinth Project
5. Condor & eagle

4. Conoco Phillips Petroleum

The company is the world's largest independent exploration and production company of Liquefied Natural Gas (LNG), with activities in 16 countries (2020c). There is close to 18450 employees and an estimated asset worth of $77 billion (Growjo, 2019a). Conoco is dedicated to effective exploration and production of O&G through innovative technical capabilities and collaborative efforts. In Australia, ConocoPhillips owns multiple offshore fields and is the second operator and producer of LNG (Table B).

Table B: ConocoPhillips production and operation locations in Australia (2020a).

Operation basins	Location	Project Description
Bayu-Undan facility	Timor Sea	Co-venturer
Darwin LNG Plant	NT	Majority interest holder and operator
Barossa Project	NT	Joint venture and operator (37%)
Australia Pacific LNG	Eastern Australia	Joint venture (37.5%)
Greater Poseidon	WA	Co-venturer (40%)
Athena	WA	Equity interest (50%)

5. Woodside Energy

Woodside has several areas of activities (i.e. exploring, developing) worldwide with operations localised in the NorthWest Shelf of Australia, and is regarded as the world's largest LNG production site. Woodside is a leader in upstream O&G operating 6% of global LNG supply (2020a). As of April 2020, the Offshore Project Proposal has been approved for gas development at Scarborough resource fields, with an offshore capacity of 7.5 MTPA (2020c). This raises concern for Australia to reach sustainability targets.

Table C: Woodside operations, platform areas and project description in Australia (2020b).

Operating Platforms	Location	Description
NWS Assets	NW Shelf, Australia	Operator Interest (16.67%)
Karatha Gas Plant (KGP)	WA	Export capacity of 16.9 Mtpa
North Rankin Complex (NRC)		Daily production capacity of up to 66,000 t dry gas & 6000 t of condensate
Goodwyn A Platform	135 km NW of Karratha	
Angel Platform	120 km NW of Karratha	
Okha FPSO	34 km E of NRC	
Pluto-A Offshore Platform	180 km NW of Karratha	Majority operator (90%)
Australia Oil Asset		Operator Interest (60%)
Ngujima-Yin FPSO	WA	production capacity is 120,000 barrels of oil a day
Greater Enfield Project		
Wheatston Project	WA	Operator Interest Wheatstone (13 %), Julimar Development Project (65%)
Scarborough Field	375 km W-NW of Burrup Peninsula	Operator of Scarborough Joint Venture (75%)

Annex 3: Description of case study Australian Ports

1. Port of Brisbane (PI)

PI is one of the largest multi-cargo ports for trade in Queensland and transports a diversity of commodities. The port is in a lease with the Queensland Government and subleases its land to other third parties (PBPL, 2019). The port is managed on behalf of the State government but is a private port, so the government does not undertake the activities at the port. The area capacity can hold 20 berths, but there is a maximum 10 vessels at a time. PI works with 80 different companies, ranging from smaller bulk item cargoes to larger cruise ships.

More specifically, the port traffic includes 2500 ships per year ranging from 100-meter ships (going to Pacific Island) to those measuring over 300 meters or a capacity of 1200 TEU containers (PortBris, 2020).

2. Port of Broome (PB)

PB is governed by the Kimberley Ports Authority (KPA). There is one main wharf and seven berths with primary customers being O&G, fuel tankers, livestock, cruise industries, and some commercial vessels. Kimberley is a key area for popular cruises and holds access to offshore rig tenders. The port has seen a small decrease in the activity in the past year (2018-2019).

3. Port of Esperance (PE)

PE is one of three ports (i.e. Albany and Bunbury) governed by the Southern Ports Authority. Main exports include nickel, iron ore and grain; main imports include fuel and fertilizer (Annex X).

4. Port of Gladstone (PoG)

PoG is a Government Owned Corporation (GOC) and is the largest multi-commodity port in Queensland (GPCL, 2019). PoG is the largest of three ports in Queensland and is governed under the Gladstone Port Corporation. The majority of trading centers on raw materials. The port's trade is mostly based on coal, representing close to 50% overall, and specifically containing 65% as coking coal for steel manufacturing and 35% as thermal coal being directed toward power plants (Sust. specialist, personal communication, January 30, 2020). There is some LNG trading and the port is looking to diversify its trades beyond the present coal, alumina and LNG to avoid reliance on bulk cargo. The port is unique in its infrastructure because it has its own power station that is mostly coal fired (and runs off the main grid) as well as an industrial centre with aluminium refineries.

5. Port of Townsville (PT)

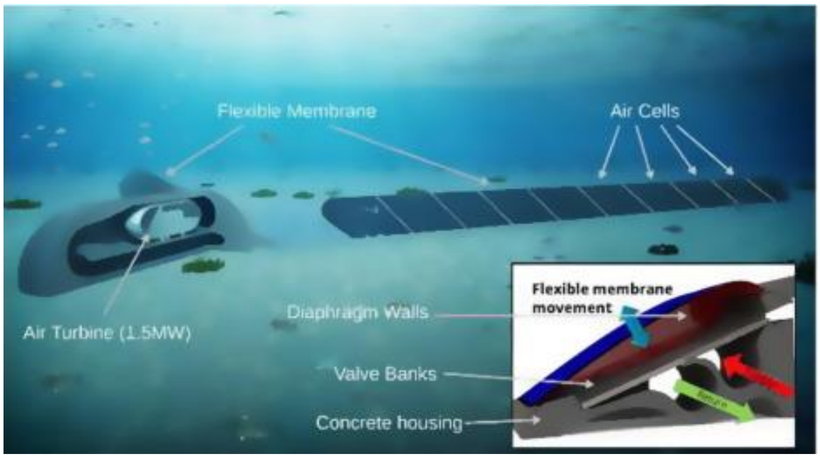
PT is managed by the Port of Townsville Limited (POTL) authority and is the largest general cargo and container port of Australia. The port is located 1300 km north of Brisbane and operates 8 berths (Port of Townsville, 2018). The port is a leading exporter of zinc, lead, sugar, fertilizer, and molasses.

Annex 4: Description of case study Technology Developer companies

1. Bombora

Bombora was founded in Western Australia and is the developer of the *mWave* modular design which harnesses the power potential of wave energy in the form of pressure (2019). The device operates on the ocean floor and is a lightweight design without exposed moving parts. The technology allows for a maximization of energy extraction across a large range of sea conditions with reduced maintenance requirements (Figure B). The device has the ability to shut down, protecting it from extreme storm events (Bombora, 2019a).

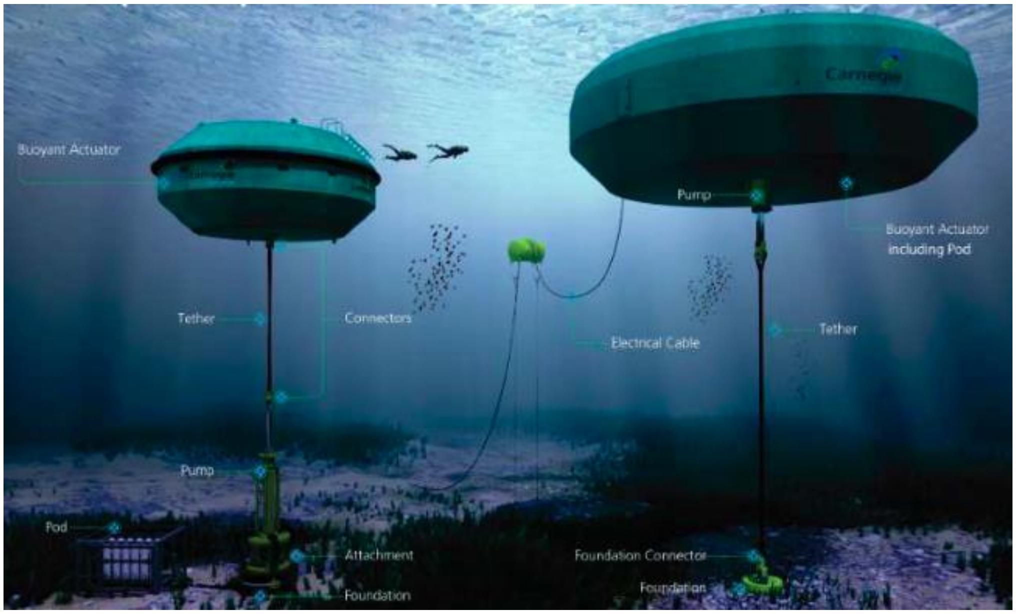
Figure B: Bombora wave power *mWave* Technology (2019a).



2. Carnegie Clean Energy

Carnegie acts as a knowledge & innovation hub, and enables prototype and equipment testing of technology performance. The company has developed the *CETO* technology which is fully submerged a few meters below the surface to harness energy and convert it into grid-connected power (Carnegie, 2020). The latest design is the *CETO 6* (Figure C).

Figure C: Carnegie *CETO* technology design (Parkinson, 2014).



3. MAKO

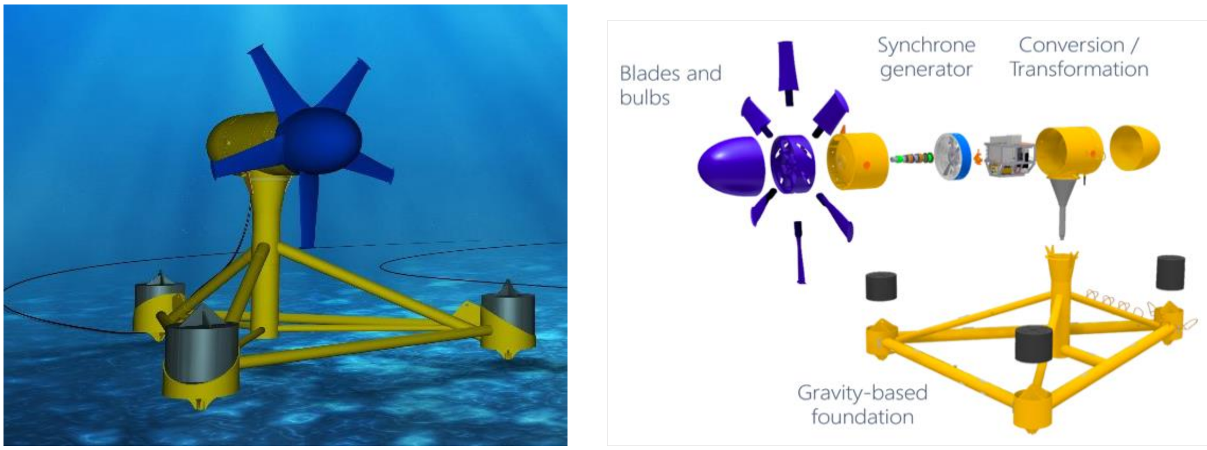
MAKO designs and manufactures hydrokinetic turbines to produce cost effective power (2020). MAKO tidal turbines are power generation system (Figure D). The technology is versatile and has been proven in several real-world operating environments and provides predictable power output (2020b).

Figure D: MAKO tidal turbine design technology (Ecogeneration, 2016).

4. Sabella

Sabella is a French company established in 2008, based in Brittany that manufactures tidal turbines (2020a). The company develops tidal stream turbines to generate clean energy from marine currents and provide a sustainable alternative to fuel-based electricity (Figure E).

Figure E: Sabella's tidal turbine design technology (2020e;2020h).



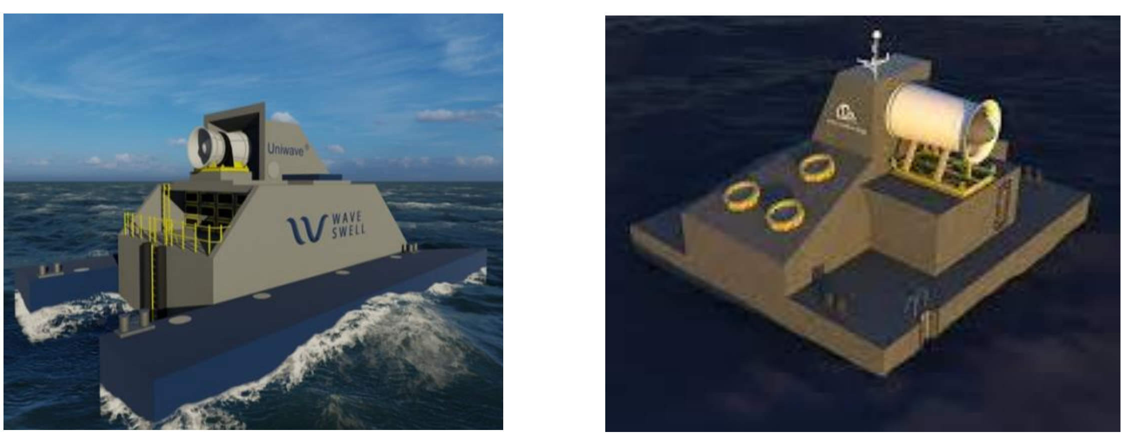
5. Wave Swell

In 2016, WSE was registered as an unlisted public Australian company to develop and commercialize the *Uniwave* technology. Their mission to provide cost-effective electrical energy from the conversion of ocean wave energy (Figure F). An advantage of the WSE technology is that it provides additional applications beyond electricity (Table D):

Table D: Applications of the WSE Technology (2019a).

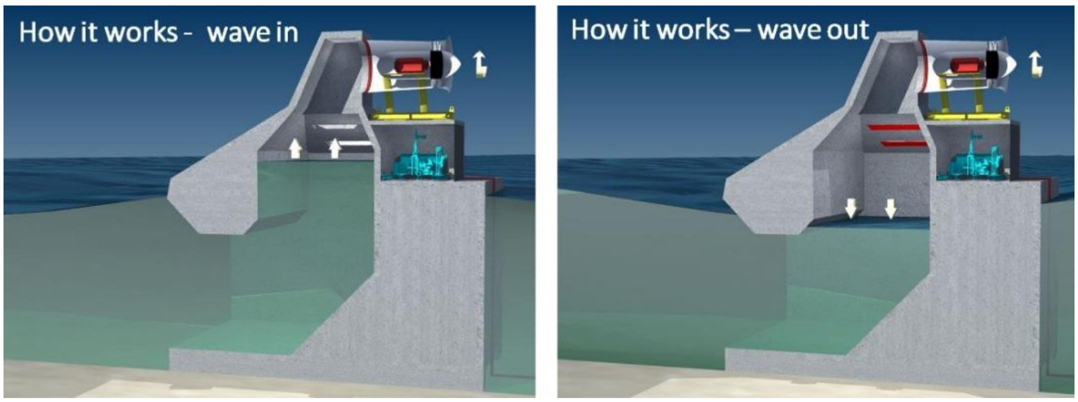
Large scale grid connected electricity
Electricity generation in remote locations
Desalination
H_2 production
Coastal protection and breakwaters

Figure F: WSE technology *Uniwave* (2019b).



The technology is based on the concept of the Oscillating Water Column (OWC) and uses a unidirectional flow design that is simple, reliable and with a higher energy conversion efficiency (Figure G). Unlike most WEC, the technology does not have moving floating units in or below the water, so the technology is more efficient at absorbing energy in waves and reduces maintenance costs.

Figure G: WSE technology with the concept of the OWC (Irving, 2017).



Annex 5: Description of case study Consultancies

10. NERA

The National Energy Resources Australia (NERA) organisation begun in 2016, and works to achieve valuable industry efficiencies and maximise the value to economy. The organisation works to ensure there are regulatory frameworks to support future investment, innovation, productivity and workforce skills. NERA plays a key role to create growth across the supply chain between energy resource sector, production facilities and technology providers for the successful energy transformation (Table E).

Table E: NERA's knowledge priorities (2020a).

Knowledge Priority	Description
1	Enhance skills and business capabilities to support automation & digitisation
2	Build talent and enable effective collaboration & innovation
3	Pursue a sustainable and low carbon energy future
4	Understand and unlock Australia's resource base
5	Develop new market & business models
6	Commercialise technology & research
7	Enhance efficiency in operations & maintenance
8	Optimise the regulatory framework

11. ATTERIS

Atteris is an engineering consultancy in subsea and pipelines. The company provides services in concept development, engineering design and analysis, execution support and decommissioning (Atteris, 2020). The interview was held with the asset lifecycle manager.

3. ORE Catapult

ORE Catapult is a consultancy that is partly funded by the (UK) government. ORE Catapult is focused on research and innovations in technology to bridge gap between academia and industry and support developing technologies (2020). The company's vision is "to be the world's leading offshore renewable energy technology centre" (ORE, 2020a). The interview was held with the Analysis and Insights Manager and Senior Researcher.

4. Pitt&Sherry

For over 50 years, the consultancy delivers sustainable solutions to industry, government and communities. The Pitt&Sherry has multiple industry expertise (e.g. transport infrastructure, mining, energy, tourism, etc.) and provide their energy users with solution development, integrated sustainable design advice, engineering and necessary regulatory approval expertise to achieve project outcomes (2020). The company holds knowledge hub and case study resources to share renewable, clean energy opportunities as well as life cycle assessments.

Annex 6: Summary of interviews

The names of the interviewees are not displayed for privacy consent and anonymity.

I. Completed Interviews

	Sector	Company Name	Interviewee Position	Date Completed
1	**Ports**	Gladstone	Sustainability Specialist	30 - 01 - 2020
2		Townsville	Manager Strategy & Sustainability	2 - 04 - 2020
3		Brisbane	Environment Manager	7 - 04 - 2020
4		Esperance	Environmental manager and environment advisory	12 - 05 - 2020
5		Broome	Health, Safety, & Environment manager	15 - 05 - 2020
6	**Consulting**	Atteris	Asset Lifecycle Manager- Business & Technical Manager	25 - 03 - 2020
7		Pitt & Sherry	Energy & Sustainability Engineer	25 - 03 - 2020
8		ORE Catapult	Senior Financial Analyst, Research & Disruptive Innovation	18 - 03 - 2020
9	**Technology Developers**	Wave Swell	Founder	04 - 02 - 2020
10		MAKO Tidal	Managing Director	22 - 04 - 2020
11		Sabella	Commercial Development Engineer	24 - 04 - 2020
12		Bombora	Commercial Manager	01- 05 - 2020

13	**Startup accelerator**	Ocean Impact Organization	Founder	14 - 02 - 2020
14	**Industry**	AOEG	Consultant – Chair	10 - 03 - 2020
15		NERA	General Manager Innovation & Strategy	19 - 03 - 2020
16	**Aquaculture**	Huon Aquaculture	Environmental Compliance & Development Manager	5 - 05 - 2020
17	**O&G**	Woodside	Senior Petroleum engineer	2 - 05 – 2020
18		Top 5 ASX	Corporate development manager	12 – 06 - 2020
19		Carnarvon	Energy & resources executive director	4 - 06 -2020

II. Declined Interviews

	Sector	Company Name	Interviewee Position
1	**Industry**- renewable energy generation	SIMEC ATLANTIS	Sustainability Specialist
2	**Industry**	SIMEC ATLANTIS	Environmental Officer
3	**Ports**	Flinders Port	Director and Strategic Advisor
4	**Consulting**	Pitt & Sherry	Environmental Consultant

III. Potential Interviews – Uncompleted

	Sector	Company Name	Interviewee Position	Contact exchange*	Request Invitation
1	**Ports**	Melbourne	Environment, Safety and Compliance	IIII LinkedIn	Accepted, no reply
2		Port Phillip	Sustainability assistant	III LinkedIn II Email	Accepted, 1 reply
3		Newcastle	Environment, Sustainability & Planning Manager	~~IIII~~ LinkedIn	
4					
5		Brisbane	Sustainability Lead	~~IIII~~ I LinkedIn	Accepted, 1 reply
6	**Aquaculture**	Petuna	General Manager	IIII LinkedIn	Accepted, 2 replies
7	**Shipbuilding**	Evolution Design	R&D Manager		

*Contact exchange is based on number of follow up messages sent (tallied).

Annex 7: Interview questions asked to key stakeholders from various sectors of the Blue Economy.

Aquaculture/O&G/Ports

1. How important are the energy costs and needs in your company?
2. What are the main constraints you are facing to meet your energy needs?

3. Does your company have a strategic goal to reduce energy costs or demand?
4. What are the motives/strategy for sustainability?
5. Do you consider renewable energy as an opportunity for the company?
6. Do you consider ocean renewable energy as an opportunity for the company?
7. What is the highest carbon price you would be willing to pay before taking approaches to adopt renewable energy technology?

Technology Developers

1. Who do you see as your customers? What is your market?
2. What is the projected capacity you are hoping to provide
3. How and when do you expect your commercialization?
4. What is your growth strategy?
5. What are the main constraints you are facing?
6. What advantages do you perceive from an integrated energy system infrastructure?

Consultancies/Organisations/Government

The following questions were asked to Atteris, NERA and Pitt&Sherry;

1. What is your experience with approaching industries and large companies?
2. Do you have an idea of the energy usage and electricity demand of energy intensive sectors in particular?
3. What are the factors for renewable energy adoption or capacity within industries?
4. What are the main constraints you have observed for industry adoption of ORE or sustainable alternative energy sources?

The following questions were adjusted to interview the consultancy, *ORE Catapult;*

1. What makes the UK a leader in ORE?
2. What are the main opportunities you have identified in the field of renewables? is it mostly export?
3. What are the main barriers you have identified in the field of ocean renewables?
4. What is your main take away for the development of ORE in Australia?

Annex 8: Summarized answers to interview questions asked to key stakeholders from various sectors of the Blue Economy.

Section 1: Industry - Aquaculture

Q1: energy costs and needs and emissions where applicable
Energy consumption

Huon	Growing fish at sea is high energy costs because operations run on diesel. Diesel consumption for fleet of (approx. 90) vessels.
Petuna	N/A
Tassal	(Year 2018) production: 30883 HOG tonne, energy demand 14.34 GJ/HOG tonne, emissions 1.04T CO2e/HOG tonne. Diesel usage is mostly for barge operations to service biomass and RO desalination (Hemer, 2019, p.4).

FY17	Energy consumption (GJ)
Diesel	200,000
Petrol	48,600
LPG	36,400
Total non-renewable	**285,000**
Electricity	158,000
Total energy use	**443,000**

Extrapolation for TSGA:
Production = 63000 HOG tonne, energy demand at 253 GWh, Diesel demand at 115 GWh (Hemer, 2019, p.4).

Summary Energy
For Huon and Tassal main energy needs is diesel for operations.

From extrapolation data projected for the TSGA there is a 45% energy demand that will come from diesel (Hemer, 2019). The calculated energy demand[7] from production in 2018 amounts to 442.86 TJ (Equation A). The calculated total emissions[8] associated with production in 2018 is 32.12 kt CO_{2-e}.

Equation A: energy usage calculation based on production and energy demand at Tassal.

$$Energy\ usage_{total} = production\ (HOG\ tonne) * energy\ demand\ \left(\frac{GJ}{HOG\ tonne}\right)$$

[7] 30883 HOG tonne x 14.34 GJ/HOG tonne = 442,682.22 GJ (Hemer, 2019, p.4)

[8] 30883 HOG tonne x 1.04 TCO_{2-e} / HOG tonne = 32 118.32 TCO_{2-e} (Hemer, 2019, p.4)

Table F: Calculated energy consumption percentage at Tassal Group from quantitative data recorded in FY17 (Author's own).

FY17	% Energy consumption of total
Diesel	70.18%
Petrol	17.1%
LPG	12.77%
Total non-renewable	(285,000 GJ)
Electricity	36%
Total energy use (incl. non-renewable)	(443,000 GJ)

Emissions

Huon	GHG per kg of salmon is lower compared to other protein producing industries (e.g. poultry, beef, lamb).
Petuna	N/A
Tassal	Diesel emissions at 66 kT CO_{2e} (Hemer, 2019, p.4). Company reports to NGER Act 2007 annually.

Summary Emissions

There are no imminent barriers because diesel is available. Feed is the highest cost constraint.

Q2: energy constraints

Huon	Feed is largest cost of operations but no real barriers because diesel is available. Past years, company has invested in expansion of infrastructure, so now working to heightened production to match expenses.
Petuna	N/A
Tassal	N/A

Summary

Huon and Tassal, are looking to develop high energy sites offshore. Strategies consider the use of technology for monitoring of operations and data records to work toward improving CO_2 footprint (i.e. energy consumption, emissions).

Q3: strategy to decrease costs or energy demand

Huon	Reduce costs of energy from supply side. Priority areas set for reducing emissions and energy consumption. Considering deploying operations in high energy sites offshore. High tech feed barges to monitor feeding behaviour, reduce feed waste, and overall CO_2 footprint.
Petuna	N/A

Tassal	Develop energy management strategies and control systems to integrate ORE systems, for example hybrid systems, storage, H_2 applications, intelligent applications to balance power supply and demand. Lease high energy sites offshore. Investigation to improve ROV technology for fish performance monitoring. Dataset on energy use and GHG emissions (Hemer, 2019, p.9).

Summary
Huon and Tassal, are looking to develop high energy sites offshore. Strategies consider the use of technology for monitoring of operations and data records to work toward improving CO_2 footprint (i.e. energy consumption, emissions).

Q4: RE opportunity?

Huon	Looking to electrify systems, collaborating with BECRC. Solar energy used to power pens and feed camera systems. To replace diesel on vessel need huge change of operations before considering RE.
Petuna	N/A
Tassal	Based on BECRC research collaboration, the objective is to identify and develop offshore RE systems for generation and storage as well as too optimise co-located offshore operations. The BECRC is working to advance the design, survivability, reliability and cost of OREC technologies (e.g. wind, wave, tidal, solar) while considering industry end-user needs. Develop multi-use and power sourced farming platforms. (Hemer, 2019, p.8).

Summary
There is collaboration with the BECRC for R&D of technology for offshore power source and electricity generation.

Q4.1: ORE opportunity?

Huon	Tidal and wave could be considered for offshore facilities to displace diesel use. First place would be on barges because generators already present (optimal for battery/H_2 storage). Unlikely to rely on ORE for onshore because grid-connected, affordable electricity market.
Petuna	N/A
Tassal	There are proven power requirements and important for diversification of energy usage. There if growing investment and capits, and the industry is established. Aquaculture is located in proximity to wave and wind energy.

Summary
Companies are considering ORE because of the geographical proximity of offshore facilities with the natural (wave or tidal) resource.

Offshore RE systems can help advance the urgency for the decarbonisation of Australia's offshore marine operations. Way to create jobs for the involved construction operations and maintenance for the RE transition in industry (Hemer, 2019, p. 10). The expected outcome is to develop marine energy conversion devices that are suited to an offshore environment and help the growth of energy export and storage, and can support aquaculture.

Q5: Motives/ strategy for sustainability

Huon	Written formal energy strategy. Company culture because from an investor's point of view there are benefits in a company with strong sustainability goals.
Petuna	Commitment is more pointed to environmental management.
Tassal	Short term (2021) goal to improve feed conversion ratio and long term (2023-2030) goal to develop higher energy farming sites.

Summary
The majority[9] of companies have a written sustainability report with written energy goals.

Q6: Carbon tax/price

Huon	NO conversation on carbon because lack of specific regulation. Company reports emissions to government. Salmon industry very regulated in Tasmania. Government plays a role to set policy and enable industry growth while protecting environment.
Petuna	N/A
Tassal	N/A

Summary
There is a lack of specific regulation. The companies report on their emissions. It is important to note that there are very strict regulations for the salmon industry in Australia.

Section 2: Industry - O&G

Q1: energy costs and needs

Note: Costs were not able to be identified neither from interviews nor from literature sources.

Energy consumption

Table G: Energy use (consumption) values for five Australian O&G case studied industries.

Company	Quantity	Year	Description	Reference
Arrow Energy	21 PJ	2012	Energy production	(Arrow, 2015a, p.81)
A Top 5 ASX Energy	0.679 PJ (679,391 GJ) 4.05 kg CO_{2e}/GJ	FY18	Net energy consumption Emissions Intensity for production	(XXX, 2018, p.36)
Carnarvon Petroleum	-	-	-	-
Conoco Phillips	64358.4 TJ	2018		(Conoco, 2018)

[9] Majority is at least two out of the three aquaculture companies under investigation

	Total energy use (combustion energy & imported electricity incl.) in Australia

Summary
Find a way to normalise and compare data.

Emissions

Table H: Estimated volume of GHG emissions for five Australian O&G case study industries.

Company	Quantity	Year	Description	Reference
Arrow Energy	99.5% 0.6% 1.076 $ktCO_2$ (1,075,654 tCO_2) 47.1 k tCO_2 (47,099 tCO_2)	2015 2012	Fuel gas Electricity Direct scope 1 & 2 Indirect scope 1 & 2	(Arrow, 2015a) (Arrow, 2015a, p.81)
A Top 5 ASX Energy	43.8 $ktCO_2$ (43,770 tCO_2) 0.37 $ktCO_2$ (367 tCO_2) 44.136 $ktCO_2$ (44,137 tCO_2)	FY18	Scope 1 Scope 2 Total	(XXX, 2018, p.36)
Carnarvon Petroleum	-	-	-	-
Conoco Phillips	4200 kt CO_{2e} 108.94 kt CO_{2e} *(37,354 t/Mmboe)*	2018	Total GHG Calculated from total operated production value *GHG intensity**	(Conoco, 2018)
Woodside Energy	8,840 $ktCO_{2\text{-}e}$ 3,302 $ktCO_{2\text{-}e}$ *9,767 $ktCO_{2\text{-}e}$* *3,535 $ktCO_{2\text{-}e}$* 7 $ktCO_{2\text{-}e}$ *8 $ktCO_{2\text{-}e}$* 74,017 $ktCO_{2\text{-}e}$ 27, 888 $ktCO_{2\text{-}e}$ 6496 $ktCO_{2\text{-}e}$ *4.45 Tj/kt* 608 $ktCO_{2\text{-}e}$ 1736 $ktCO_{2\text{-}e}$	2019 *2018* 2019 *2018* 2019 2019	Scope 1 - Equity Scope 1 - Equity Scope 2 Scope 3 - equity Fuel emissions *Fuel intensity* Flare emissions Venting emissions	(Woodside Sustainability Data Hub, 2020)

**GHG intensity is the rate of GHG emissions equivalent to CO_2 per unit of electricity produced (Arrow, 2015a).*

Summary

Given the small size of company, Carnarvon has yet reported public information on resource use and/or GHG emissions.

From data information found at Woodside, there is an overall reduction in resource use and intensity from 2018.

Arrow energy categorizes the company's GHG emissions sources into scope 1 and 2 (Table C). Fugitive emissions are the second largest contributor of scope 1, after the combustion of CSG (Coal Seam Gas) for power generation.

From looking at Table B and C suggest the following chronological order, from highest to lowest volume, for both energy use and GHG emissions. There is a similar pattern in terms of the revenue earned per company that may explain the correlation in energy demand and emission output (Table I).

Table I: Comparison and trend of energy use, GHG emissions and revenue earned from highest to lowest value for Australian O&G industries.

	Energy use	**GHG emissions**	**Company**	**Revenue (USD) million**
highest	1. ConocoPhilips	1. Woodside	1. ConocoPhilips	38,727
	2. Woodside	2. ConocoPhilips	2. Woodside	3,908
	3. Arrow Energy	3. Arrow Energy	3. Top 5 ASX	1,5014
	4. Top 5 ASX	4. Top 5 ASX	4. Arrow Energy	243.6
lowest	-	-	5. Carnarvon	5.7

Q2: constraints to meet energy needs

Arrow Energy	For projects need government issued petroleum tenure and license to construct and operate (pipelines)
A Top 5 ASX Energy	No significant barrier to consume oil and gas produced. Minimise losses and expense of volume not sold to market – profit margin
Carnarvon Petroleum	Electricity needed for onsite power generation at cost of volume unsold.
Conoco Phillips	Contingent sources volume
Woodside Energy	provision of gas that must be sold domestically entails lower profit margin

Summary
The most common[10] constraint shared is the trade-off of electricity for own site operations and use or the quota for domestic sales against potential profit margin earned.

Q3: strategy to decrease costs or energy demand

[10] Most common/majority is at least three out of the five oil and gas companies under investigation

Arrow Energy	Natural gas is fundamental energy source for power and helps reduced GHG emissions (compared with other fossil fuels). Reporting under NGER Act 2007
A Top 5 ASX Energy	Reporting under NGER Act. Integrate low emissions technologies in operations given economic viability. Emission reduction projects (solar, CC). Mostly CSR because no big constraint or carbon cost.
Carnarvon Petroleum	Costs determine strategy for RE. Remain competitive on global market. Expanding operations (drilling and new wells). Lower emissions, cost-effective.
Conoco Phillips	Seek low carbon alternatives. Executive team mindset. Reporting under NGER Act. Engaged in emission reduction measures (target scope 1 & 2). Near-term technology investments for long term payback benefits. Scenario planning. 37.0 kg/BOE-33.kg/BOE emission reduction target for 2018. For 2030: reduce emission intensity from 5% to 15%. 2050: carbon neutral.
Woodside Energy	Natural gas is important solution for energy demand because displaces higher emissions fuels. Target 2019:4% EEI against baseline (5% by 2020) (energy efficiency improvement), reduce GHG emissions 7 thousand tonnes per year. 2050: carbon neutral.

Summary
The majority of companies report emissions under the NGER Act. There is consideration of technology and investment to reduce GHG but it is a factor of economic viability (e.g. PBP) for the final decision making.

All companies have annual published sustainability report except Carnarvon has annual report and no sustainability directives.

Q4: RE opportunity?

Arrow Energy	
A Top 5 ASX Energy	Yes, but site and application potential. Government support (subsidy, incentive)
Carnarvon Petroleum	Lack of government incentive. Possibility for RE: Solar farm or CCS.
Conoco Phillips	
Woodside Energy	Yes, for now solar and wind because suited to Australia.

Summary
The majority of companies responded “yes”. The common view is that there is an opportunity to implement RE, though mostly solar is considered a possibility for O&G companies because of reliability and affordable market electricity price.

Q4.1 ORE opportunity?

Arrow Energy	Value environment, produce clean energy.
Top 5 ASX Energy	Focus on successful transition. ORE low on radar for industry because high cost and risk, reliability issues. Need proven, mature technology.
Carnarvon Petroleum	Limited opportunity for RE. Focus is competition and cost so alternative energy type does not matter. Additional cost because dynamic, unpredictable environment. Disappointments of past ocean demonstration projects.
Conoco Phillips	Technology is important for GHG emissions and lower EI. Near term tech investments
Woodside Energy	Need for larger scale projects of ORE to meet energy demand of O&G. not considered strong opportunity because need more developed technologies. Capital risks. Limited understand for installation mechanism and suitability to operation platform.

Summary
The majority share that there is limited opportunity because of capital risks, costs and the need for further development as well as larger scale project. The main issue perceived is the reliability of the technology.

Q5: carbon tax

Arrow Energy	Integrated in business process to leverage future opportunity for EE and emissions reduction.
Top 5 ASX Energy	Models internal carbon price to drive decisions. Looking at outlook of price than threshold. Government allows companies to adjust baseline upwards (expansion project).
Carnarvon Petroleum	Issue Tax will encourage focus on cost rather than particular technology. Government relies on export earnings of LNG.
Conoco Phillips	No carbon tax in AU. Company integrate theoretical carbon price of cost of compliance in climate risk mitigation scenarios.
Woodside Energy	In a project, potential carbon price taken into decision making. NO official legislative pressure,

Summary
There is an integrated theoretical carbon price in the decision making and models. There is a lack of government restrictions, for example companies can adjust the baseline of emissions upwards.

Section 3: Industry - Ports
Q1: energy costs & needs and emissions where applicable

Brisbane	Office consumption, lighting. Supply from main grid. No scope 3 emissions accounting

Broome	Energy own use and port tenants. Energy tracking is for equipment that run on diesel (e.g. cranes). There is limited energy use management.
Esperance	Energy use expected to increase by 50% because main client will increase ore exports.
Gladstone	Port operations and facilities. 98% energy use because of coal terminal.
Townsville	Baseline for direct energy consumption (e.g. vehicles, buildings). Largest emissions from daily activities (office and transport). Scope 1 & 2 emissions recorded, working to include customer energy use.

Summary
Costs were not identified.

The main energy usage is for operations [equipment, transport], facilities [buildings] and direct consumption [lighting].

Q2: constraints to meet energy needs

Brisbane	None. Fuel energy pricing
Broome	No issues. If main power supplier makes changes to metering may incur additional costs.
Esperance	None. One supplier for main power station
Gladstone	Looking to diversify present energy mix. Locked into long-term energy contract
Townsville	None, low energy need unless expand.

Summary
The majority[11] of ports identify no issues. Constraint will depend on factors of fuel pricing, main supplier decision and time frame of locked-in electricity contracts.

Q3: strategy to decrease costs or energy demand

Brisbane	Emissions reduction internally. Reduce fuel consumption on vessels. Focus on efficiency
Broome	No plan yet, strategies to reduce energy use. Small port so no requirements to report carbon emissions
Esperance	Alternative energy sources project will depend on budget. Energy savings included in installations.
Gladstone	Aspire to SDGs for guidance
Townsville	Solar project for energy consumption

Summary
A focus is to look at efficiency, through energy savings, and reduce consumption by incorporating alternative energies.

[11] The majority is at least three out of the five ports under investigation

Q4: RE opportunity?

Brisbane	Yes, Seeking ways to increase investment in RE. Working on private locally sourced RE and create microgrid framework. Incorporate storage system. Focus on solar because cheap cost and suitable to spatial layout. Solar panel car park for cruise ship terminal (800 kW capacity).
Broome	Need economy of scale and technology analysis to consider appropriate RE.
Esperance	Reporting energy use and emissions reduction strategy. Locked in energy contract to limited opportunities. Solar project in development.
Gladstone	Small scale RE adoption (solar) affordable and available from electricity grid.
Townsville	Considering H_2 as a potential energy source.

Summary

The majority of ports are developing solar projects. Ports are considering the potential for alterative RE but securing enough allocated investment is difficult because grid-connected electricity is available at a cheap cost.

Q4.1: ORE opportunity?

Brisbane	Pilot project with Eco Wave Power. Slow process because not commercial, expensive technology, concern on volume output. Multiple unanswered questions and concerns (frequency, grid connect, attachment).
Broome	Good tides – average 3.6m levels. Need for investment for infrastructure to install tidal or wave tech.
Esperance	Port records data for waves current and tides at its different locations, but small tides. Opportunity to collaborate with WERC – Wave Energy Research Center at UWA (Albany).
Gladstone	No defined process for installation or interacting with regulators. Solar and wind have commercial competency and grid connect (large power supply). Collaboration with Mako for 6-month trial demonstration project proved potential to use port infrastructure. Long arduous process for installation and approval of ORE. Businesses have lack of knowledge.
Townsville	Not viable because not cost effective. Concerns on reliability of tidal technology. Tidal needs to undergo learning curve and reach comparable scale of power generation (GW). General limited knowledge of ORES. Potential for wave energy.

Summary

There are opportunities for collaboration (past and present). ORE is not viable because it is not commercial and there is competency of volume output with traditional RE (e.g. solar and wind). It is a long process for installation and there is a general limited understanding and knowledge of tidal and wave technologies.

Q5: motives/strategy for sustainability

Brisbane	Separate branch responsible for sustainability. 24% emissions reduction by 2024-25. Net zero emissions by 2030. Current installed solar capacity (100 kW)
Broome	Complement sustainability best practices. No plan yet. Improve performance.
Esperance	Part of team culture. Motive to install solar for own source of consumption and complement grid. Annual environment management program but limited focus allocated on sustainability.
Gladstone	Societal responsibility (CSR). Identifying priority areas for overall reduction goal. Potential for ship to shore power to displace diesel use. Monitoring of hydrocarbon use and electricity to improve energy and GHG performance. Current efforts are efficient lighting and fuel efficiency specification for vehicle fleets.
Townsville	Projection scenarios and themes aligned with UN SDGs. Baseline audits to integrate RE and reach carbon positive and 100% RE. Avoid having to offset emissions.

Summary
There are efforts for sustainability but it is not necessarily a priority. Some measures include lighting efficiency, emission reduction and carbon positivity goals. Ports are taking into account GHG performance and following SDGs for guidance.

Q6: carbon tax

Brisbane	Unsure. Project evaluated on commercial energy price
Broome	Maximum $AU100 million to offset carbon where $AU5 million if offset payment and the other half for RE infrastructure. Beneficial to calculate Net Present Value to estimate ROI and PBP.
Esperance	N/A
Gladstone	N/A
Townsville	N/A

Summary
Limited information available or not discussed.

Section 4: Technology Developers

Q1: customer market

Bombora	Utilities, niche market, private dev
Carnegie	Micro-grid communities, Dept of Defense, naval base
Mako	Small-scale, secondary ports, overseas, deep ocean offshore, off-grid. Bridges and wharves for their existing infrastructure.
Sabella	Off-grid communities, isolated geographical networks
WaveSwell	Project developers, ports & harbors, all industries

Summary
Small-scale, micro-grid communities, ports and offshore (i.e. existing infrastructure).

Q2: projected capacity

Bombora	1.5 MW prototype, Collocate offshore, scale up to 20 MW (2030) 3MW wave park
Carnegie	1.5 MW capacity, grid connected system prove, and multiple array system. Micro-grid communities, Dept of Defense, naval base Integrated RE microgrid with wave, solar, battery Project of 20 MW wave farm
Mako	Asian market, scaling on wharves and bridges Single mini turbine now toward multiple array to meet grid demand
Sabella	Small scale pilot farm, up to multiple units for planned capacity of 2-3 MW. Reduce fossil fuel dependence for Island community with multi-energy integrated project. 1 MW turbine in Pembrokeshire island
WaveSwell	Remote coastal areas 200 kW on Island to complement wind and solar grid – diversify energy mix and diesel consumption

Summary
Shorter term capacity (1.5-3MW) to a projected capacity of 200MW. Working to scale up and meet grid demand (e.g. multiple array, farms). Expand the possibility to integrate multiple energy sources to displace fossil fuel use and diversify energy mix.

Q3: Commercialisation forecast

Bombora	Low-impact WEC projects in Europe (UK, Portugal) & Australia (Western). Grid connection, 60 MW wave farm. Array of 1.5 converters.
Carnegie	In-ocean operational testing. Own testing facility in Pembrokeshire, Wales.
Mako	Diversity of site infrastructure (barge, bridge, wharf) and geographical locations (Australia, Japan, Singapore). Reliability in low tidal flow and lower cost per kw.
Sabella	Secure commercial potential by reinforcing/optimizing tech reliability. Secure power generation availability. Decrease O&M costs.
WaveSwell	Validate performance of tech and economic viability. Expect to start commercial phase with LCOE below 10 cents per kW.

Summary
There are testing facilities to validate technology reliability, secure commercial potential and achieve lower costs (e.g. move along curve), to ensure economic viability.

Q4: Growth strategy

Bombora	Target large sites to attract financial institutions' interest. First full scale mWave design 2017. Achieved feasibility study for 60 MW wave farm
Carnegie	Funding received to continue progress: Construct virtual prototype, forge commercial partnerships, reach competitive cost level, partner with utility scale sector.
Mako	Engineering facility and equipment ownership for direct fabrication and prototype testing. Confirm durability and ability of power generation in variety of flow conditions. Displace competition with solar offshore. Build ties with aquaculture and find appropriate tidal flow locations
Sabella	Build interconnected sites with multiple unit arrays. Work to reduce costs (by moving from demonstration project (1 unit) to pilot farm (2-10 units) and then reach commercial scale. De-risk technology and obtain volume effect
WaveSwell	Replace diesel in isolated areas like remote pacific islands (near-term) and compliment base load power for large scale grid connected areas (future term). Spread knowledge and publicize technology.

Summary
Prototype testing. De-risk and improve durability of technology. Form partnerships to achieve commerciality and competitive costs.

Q5: Constraints/difficulties in company

Bombora	Deliver cost effective energy. Ensure durability of device in harsh environment. Need for government/public support mechanisms.
Carnegie	Provide evidence of capacity to deliver offshore connected to onshore power unit.
Mako	Designing cost-effective technology Working in array of environmental conditions Prove generation of predictable energy. Competitive price with grid power.
Sabella	High cost of investment and maintenance. Lack of funding and limited insurance. High risk level technology and projects have long time frames
WaveSwell	Competitive advantage of wind and solar (well connected to grid and cheap price).

Summary
There is a lack of funding and government support. There is an urgency to achieve cost-effective technology given the high risk, difficult environment and capacity potential of other available electricity supply sources.

Q6: integrated energy system advantages

Bombora	Lower project costs, continuous source of power.
Carnegie	Reduced intermittency in energy system.
Mako	Battery storage, shared expense.

Sabella	Lower overall risk of projects. Identify optimal multi-energy use source model. Multi-source energy mix can lower cost of energy per Mwh and reduce GHG emission impact.
WaveSwell	Increase renewables in energy mix can optimize geographic diversity and help build capacity of wave technology

Summary

Helps to lower costs and overall risks of projects. Integrated energy systems build capacity and ensures continuous source of power.

Q7: Main take-aways from projects

Bombora	Perform risk register. Working with ports gives infrastructure advantage.
Carnegie	Reliable power is possible with microgrid. Multiple sources of energy can enable high peak load power.
Mako	Link up with customer and other service providers. Prove reliability of technology through robust data set.
Sabella	Long time for projects to start.
WaveSwell	Demonstration projects help to publicize and better understand the technology.

Summary

Collaboration with industries and service provides reinforces understand of technology and advances reliability of ORE in different contexts.

Section 5: Consultancies/organisations

Q1: experience with large companies

Atteris	Work mostly with O&G sector. ROPE project in partnership with MAKO and AOEG to test application of turbines for industries
NERA	Conversation with energy sector to improve efficiencies. O&G industries are traditional but slow movement to work on reducing own energy consumption.
ORE Catapult	Funding from UK government has allowed the company be a leader in research and innovation on offshore RE. Consultancy owns test and demonstration facilities which has welcomed portfolio of projects and services across industries from around the globe.
Pitt&Sherry	Companies do not want to spend energy efficiency procedures but are happy to have done it (e.g. if government covers the costs).

Summary

Partnerships and projects with industries is important to lead research and testing. Companies are reluctant to spend/invest significantly without funding.

Q2: factors/opportunities for RE

Atteris	Potential to decommission current platforms with tidal power. Need reliable technology, less expensive energy.
NERA	Main push is because of CO_2 footprint, scope 1 & 2 emissions. Potential for solar because little maintenance and the technology is proven.
ORE Catapult	Opportunity in auxiliary markets.
Pitt&Sherry	CSR strategy and increased in gas prices. Need for large government undertaking and disseminating research.

Summary
Possibility to decommission current platform or connect with auxiliary markets. There is a need for government undertaking. The main motive is CO_2 footprint strategy.

Q3: Energy usage and electricity demand of industries

Atteris	High energy intensity in O&G. 24/7running of operations
NERA	Main power demand for facility, pumps and electrical processes. Gas transport from offshore to shore.
ORE Catapult	N/A
Pitt&Sherry	Dependent on processes per sector (e.g. process heating).

Summary
Energy intensity depends on the sector main operations, process and type of facility.

Q4: constraints/barriers for ORE in industries

Atteris	Need for 100% reliable energy for hydrocarbon production. Current power output is too small, particularly for offshore.
NERA	Large technology gap and slow process. Concern of reliability and potential for MW output to meet base load requirements (in O&G industry). Infrastructure offshore needs to be in place and resilient to harsh environment
ORE Catapult	No standard installation process of ORE. Difficult environment. Limited financial policy. Solar dominates electricity market.
Pitt&Sherry	Companies care to improve business and will not engage if an technology is too capital intensive.

Summary
Higher reliability is needed and a sufficient power output. It is a harsh environment and there is no standard for procedure (e.g. installation, infrastructure).

Q5: take away message for ORE dev in Australia

Atteris	Slow progress, O&G companies are cautious but want to find ways to supplement their energy demand. Possibilities may lie within niche markets and smaller unit operations.
NERA	For a change to occur there is a need of an external threat. Sustainability mindset (e.g. alternative energy mix, reduce energy consumption) is growing in O&G sector
ORE Catapult	Need for financial support. Build network between stakeholders and enterprises. De-risk investments.
Pitt&Sherry	Interest in ORE is dependent on the 'off the shelf' price. Industry groups are pushing for innovation and long-term sustainability.

Summary
Companies are cautious. A sustainability mindset is growing. There is potential for networks between stakeholders and industry groups to aid innovation and integrate smaller scale markets (e.g. unit operations).

Q6: difficulties in company

Atteris	Most companies looking for Engineering Procurement and Construction – EPC- service butt Atteris is only involved in Engineering (majority of value in P&C).
NERA	RE energy sector is very slow process and it is difficult to change the BAU paradigm within O&G industries.
ORE Catapult	N/A
Pitt&Sherry	High dependence on government for grants and funds to carry out feasibility studies and projects. Difficult to obtain clients and follow through.

Summary
Sector in RE is slow and communication with potential clients is difficult.

Annex 9: Interview References

1. **Aquaculture**

Huon: (Environmental Compliance and development manager on May 5, 2020)
Petuna: N/A
Tassal: N/A

2. **O&G**

A top 5 ASX: (Corporate development manager, personal communication, June 12, 2020)
Carnarvon: (Energy & resources Executive Director, personal communication, June 4, 2020)
Woodside: (Senior petroleum engineer, personal communication, May 2, 2020)

3. **Ports**

Port of Brisbane: (HSE manager, personal communication, May 15, 2020)
Port of Esperance: (Envr. manager & envr. advisory, personal communication, May 12, 2020)
Port of Brisbane: (Envr. manager, personal communication, April 4, 2020)
Port of Gladstone: (Sust. specialist, personal communication, January 30, 2020)
Port of Townsville: (Manager strategy & sust., personal communication, April 2, 2020)

4. **Tech Dev**

Bombora: (Commercial Manager, personal communication, May 1, 2020)
Carnegie: N/A
MAKO: (CEO, personal communication, April 22, 2020)
Sabella: (Commercial Development Engineer, personal communication, April 24, 2020)
Wave Swell: (Commercial Manager, personal communication, May 1, 2020)

5. **Industries**

ATTERIS: (Asset Lifecycle Manager, personal communication, 25 March 2020)
NERA: (General manager innovation and strategy, personal communication, 19 March 2020)
ORE Catapult: (Analysis & Insights and Senior Mng. Researcher, personal communication, 18 March, 2020)
Pitt&Sherry: (Energy & Sustainability Engineer, personal communication, 25 March 2020)

6. **Government**

AOEG: Government and policy specialist, personal communication, 11 February 2020)

Annex 10: The following figures and tables display energy consumption and emissions related data to the **Aquaculture sector**.

Table J: Energy input ratio per operational component for intensive salmon cage farming operations (Troell et al., 2004).

Operation component	Energy Ratio [kJ/kg]
Equipment	5940
Feed	78210
Electricity, fuel	11880

Table K: Extrapolated energy input for salmon (intensive cage) farming in GJ for the FY2018-19 of three Australian Aquaculture companies interviewed (reference data Troell et al. 2004) (Author's own).

FY18-19	Salmon production Energy (GJ)			
Company	**Equipment**	**Feed**	**Electricity, fuel**	**Total (GJ)**
Tassal	191012.58	2514998.97	382025.16	**3088036.71**
Huon	111778.92	1471755.78	223557.84	**1807092.54**
Petuna	35717.22	470276.73	71434.44	**577428.39**

Table K represents the energy input per operation component for Tassal, Huon, and Petuna in the year 2018-2019. This financial year is chosen for greater accuracy of quantitative results because the volume production values are in absolute terms, directly from the literature and not based off an estimated calculation, as it is in Table L for the year 2019-2020.

Table L: Summary of calculated energy usage expressed in TJ in 2019 and 2020 for three aquaculture companies interviewed (Author's own).

Company	**Financial Year**	**Energy Demand [TJ]** (Hemer, 2019)	**Diesel Demand [TJ]** (Hemer, 2019)	**Total Energy [TJ]** (Troell. et al., 2004)
Tassal	2019	461.2	207.4	3088.1
	2020	505.4	227.5	3385.8
Huon	2019	270.0	121.3	1807.2
	2020	392.4	176.4	2626.9
Petuna	2019	86.4	38.9	577.4
	2020	107.3	48.2	718.2

Table M: ORE power potential estimated for three Australian Aquaculture companies in 2019 and as of 2020.

FY2019	**ORE Power Potential [MW]**		
Company	**Lower limit**	**Mid-range**	**Upper limit**
Tassal	0.63	1.84	2.3
Huon	0.37	1.08	1.35
Petuna	0.12	0.35	0.43

FY2020	**ORE Power Potential [MW]**		
Company	**Lower limit**	**Mid-range**	**Upper limit**
Tassal	0.70	2.02	2.53
Huon	0.54	1.57	1.96
Petuna	0.15	0.43	0.54

Figure L: Potential power generation for tidal and wave technology calculated in 2019 for Australian aquaculture companies (Author's own).

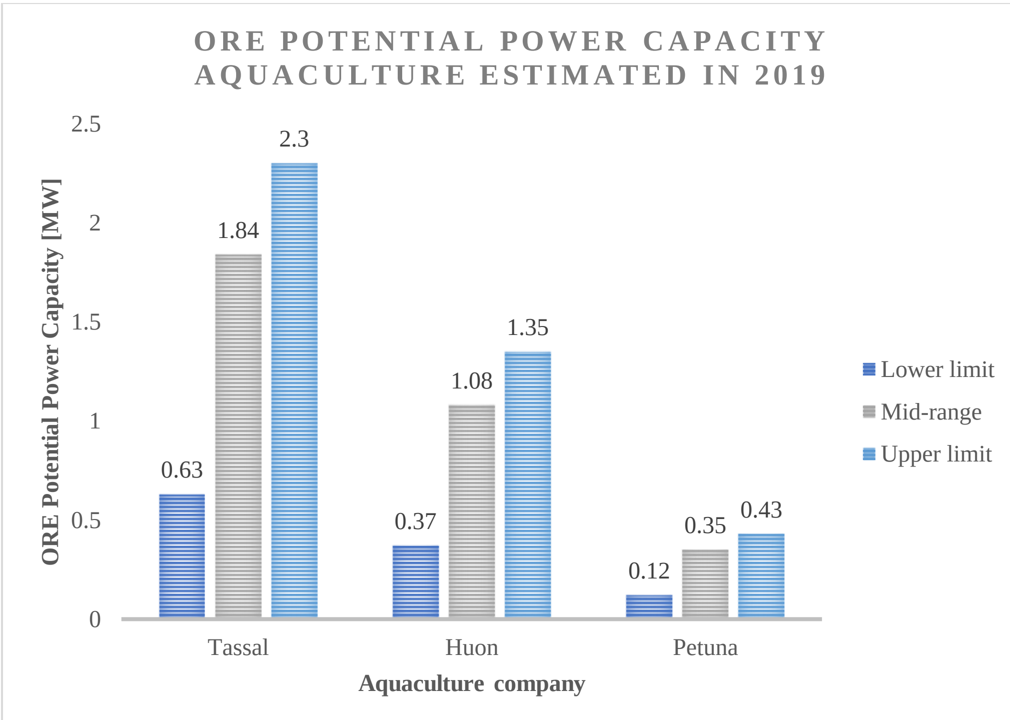


Table N: Calculated emission abatement from electricity with ORE technology in Aquaculture companies in Australia in 2019 and 2020 (Author's own).

Company	Financial Year	Emission abatement from electricity	
		Lower limit [kt CO2]	Upper limit [kt CO2]
Tassal	2019	829.6	1079.8
	2020	909.3	1183.5
Huon	2019	485.7	632.2
	2020	705.9	918.8
Petuna	2019	155.4	202.3
	2020	193.0	251.2

Table O: Calculated emission abatement from diesel with ORE technology in Aquaculture companies in Australia in 2019 and 2020 (Author's own).

Company	Financial Year	Emission abatement from diesel [kt CO2]	
		Lower limit	Upper limit
Tassal	2019	1036.2	1347.9
	2020	1137.0	1478.9
Huon	2019	606.3	788.6
	2020	881.5	1146.6
Petuna	2019	194.3	252.7
	2020	241.1	313.6

Annex 11: The following figures and tables display energy consumption and emissions related data to the O&G sector.

Table P: Estimated number of employees in five O&G companies case studied (Growjo, 2019, a,b; Woodside, 2020a, ZoomInfo, 2020).

Company	Number of employees
Arrow Energy	750
Top 5 ASX company	600
Carnarvon	34
Conoco Phillips	18 450
Woodside	3 834

Table Q: Resource use per category type at Woodside in 2018 and 2019 (Woodside, 2020, Sustainability Data Hub).

	2019	2018
Type	**Resource use (TJ)**	
Total fuel consumption - equity	45,490	48,936
Total fuel consumption	129,412	140,433
Type	**Electricity consumption (TJ)**	
Grid electricity consumption	37	43
Type	**Hydrocarbon production (kt)**	
Total - equity	10,293	10,389
Total	28,618	30,283

Note: Equity resource consumption is the amount from operations according to its share of equity in the operation. In a joint venture the partners have joint financial control (GHG Protocol, 2013).

Table R: O&G expected development projects in Australia from 2019 to 2023 (Nicholson, 2019).

Project Title	**Operator**	**Value / starting year**	**Resources**	**Description and yield**
Browse Upstream Development	Woodside Petroleum	$15 billion / 2023	15.4 trillion cubic feet dry gas, and 453 MMbls of condensate.	Develop two 360m long, 90,000 tonne gas clotting production storage and offloading (gFPSO facilities). Deliver ~10 mtpa of gas to NWS existing infrastructure
Browse Basin Satellite Fields	Conoco Phillips	$10.4 billion / 2021	Three basin Satellite: Poseidon, Kronos and Boreas.	Develop an LNG plant to obtain between 3 trillion and 15 Tfc of gas. Option to develop semi-sub production platform, a 30" 230 km pipeline to the riser platform and a 40" 770 km pipeline to Darwin.
Surat Gas Project	Arrow Energy	$7.15 billion / 2020	Use existing infrastructure owned by QGC to transport gas to domestic and export markets.	18 production facilities, expected to yield 4 Tcf of gas over next 27 years with 4mtpa during peak production.
Gorgon LNG Train 4		$5.1 billion / 2020	Current daily production 18,000 barrels condensate.	Expansion to add a fourth 4.5 million tonne/year capacity LNG train and a storage tank and third pipeline.
Conoco Phillips Barossa Project	Conoco Phillips	2023	Use FPSO 9 development wells and over 260km of subsea pipeline.	Two phases of development: 1st: six wells from three subsea locations. 2nd: after 8 years of start-up will involve four wells.
Pluto LNG Train 2	Woodside Petroleum	$5 billion / 2023	Current capacity 4.9 mtpa processed from offshore Pluto and Xena gas fields.	Expansion to add a 2nd LNG liquefaction train, capacity of 5-7 mtpa using gas feedstock from Scarborough field.
West-East Gas Pipeline	Proposed by the government	$5 billion / 2022		West-East Gas pipeline will cover 2900km route from Karratha to Moomba.
Prelude, Tocatta and Concerto Gas Fields (CO2)	Shell	$4 billion / 2019	Use existing infrastructure owned by QGC to transport gas to domestic and export markets.	
Burrup Peninsula Urea Project			Currently under a memorandum of understanding phase. Urea fertiliser manufacturing using natural gas from the Scarborough field.	2 million tonnes per year of urea, export market to Asia Pacific.
Tassie Shoal Gas-to-Methanol Plant	Melbana Energy	$2 billion / 2021		Two separate facilities to produce methanol. Each will require about 200 MMcf/d of feed gas to reach a production of 1.75 mtpa methanol. Build a concrete structure to store 100.000 tonnes.

Abbreviations *MMbls:* million barrels - *(g) FPSO:* (gas) floating production storage and offloading - *MTPA:* million tons per annum - *Tfc:* trillion cubic feet - *MMcf/d*: million cubic feet per day.

Table S: Extrapolated power capacity potential for ORE sourced electricity from 2018 to 2020 in O&G sector (Author's own).

	ORE capacity from electricity (GWh)		
Company	**2018**	**2019**	**2020**
Top 5 ASX	0.02	0.02	0.03
Conoco	1.65	2.01	2.45
Woodside	3.60	4.39	5.35

Table T: Calculated emission abatement from electricity with ORE technology in O&G companies in Australia in 2020 (Author's own).

Company	**Emissions abatement from electricity [kt CO2]**	
2020	Lower limit	Upper limit
Top 5 ASX	1.3	1.7
Conoco	126.1	164.2
Woodside	275.2	358.2

Table U: Scope 1 and 2 operated emissions by source in 2018 and 2019 at Woodside (2020).

Source operation	**Year**	**Emissions** (kt CO_{2-e})
Fuel combustion	2018	7048
	2019	6496
Flare	2018	696
	2019	608
Venting	2018	2021
	2019	1736
Other	2018	1
	2019	1

Figure H: GHG emissions by source at Woodside in 2019 (Woodside, 2020).

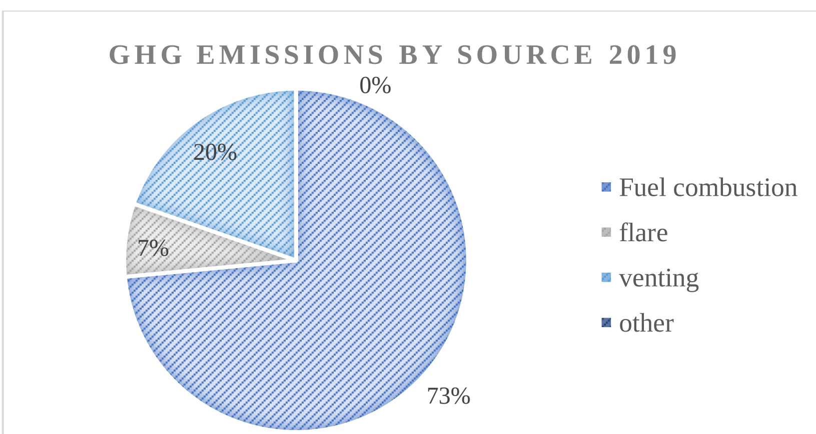
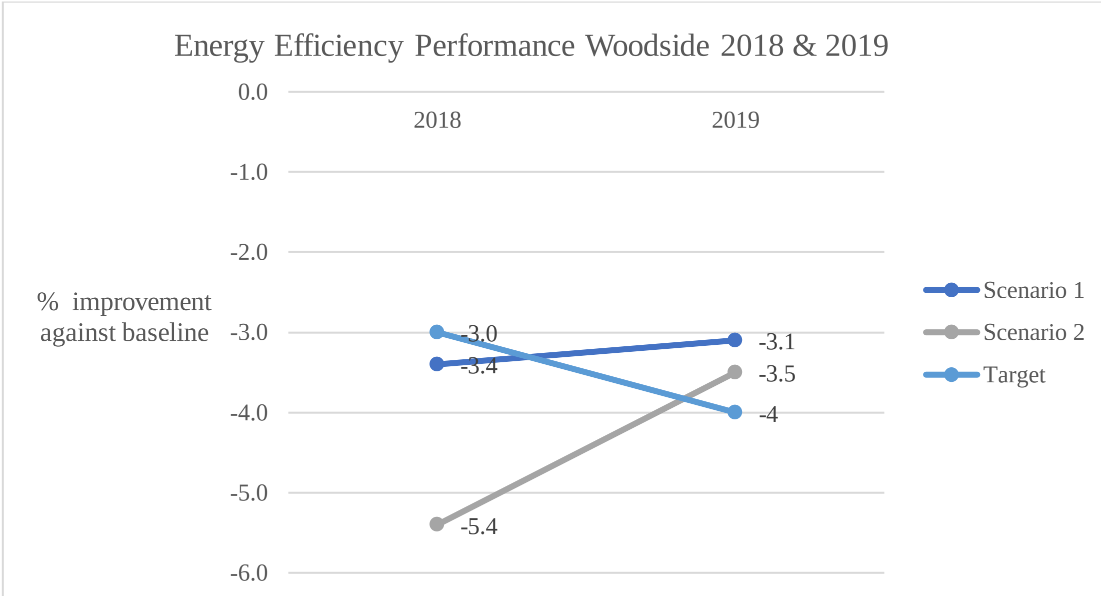


Figure I: Energy Efficiency performance at Woodside in 2018 & 2019.



** Scenario 1: performance against baseline.
** Scenario 2: Performance against baseline excluding impacts.
** Target performance is 5% energy efficiency improvement by 2020 against baseline.

Annex 12: The following figures and tables display energy consumption and emissions related data to technology developer companies.

Table W: Technology developer companies and description of pilot demonstration projects and projected capacity from now into the future (Bombora 2019a,b,c,d,e,f).

Company	Project Description	Timeframe
Bombora Wave Power	Device pilot testing and project demonstration. 1.5 MW capacity in Pembrokshire, Wales (nearshore).	2017 (6-12 months)
	Test integrated island power supply. 2 MW capacity located along coastline in Canary Islands, Spain.	2020
	Commercial deployment proofing and objective to connect to grid. Located at Orkney Island UK EMEC site.	Future
	Objective to build 60 MW generating capacity wave farm in Peniche, Portugal.	Future

Table X: Technology developer companies and description of pilot demonstration projects and projected capacity from now into the future (Carnegie 2020a,b,c,d,e,f,g,j).

Company	Project Description	Timeframe
Carnegie CETO 6	Small scale commercial array testing of 1-10, 1.5 MW mWave converters. Objective to install 40 devices for commercial rollout (supply 14,000 homes).	Future
	Integrated renewable microgrid connected to wave site offshore with 2MW solar capacity battery. Garden Island, WA.	2019- current
	CETO 5 device pilot testing for components, array planning, installation and maintenance. Located 16 km offshore at Wave Hub, UK.	signed MOU*
	CETO 6 demonstration project in Albany, WA, funding withdrawn.	2017
	First demonstration of complete grid connected CETO system with 3 units providing electricity generation and desalination capacity in Garden Island, WA.	late 2014 (for 12 months)
	Idea proofing of an isolated grid system integrating multiple energy sources to reach peak load of 378 MW, with current 22% RE, near-term 35% and long term 50% RE in Mauritian Island of Rodrigues.	Contracted, government funding

*Memorendum of Understanding

Table Y: Technology developer companies and description of pilot demonstration projects and projected capacity from now into the future (MAKO 2020a,b).

Company	Project Description	Timeframe
MAKO Tidal Turbines	Demonstration of tidal technology system in Singapore.	2019
	Testing for customer.	2019
	Tidal turbine trial testing at PoG, QL.	2018 (6 months)
	Demonstration of tidal turbine at Bougainville, Papau New Guinea.	2017
	Research with AMC-AUSTEn Program to map and quantify Australia's tidal energy sources.	2016
	Tank testing to validate MAKO turbine design and performance.	2016
	New manufacturing for low-volume production phases in Sydney.	Sep.. 2015
	First sea trials of MAKO device at Sydney Harbour.	Nov. 2014
	New design prototyping and testing for low-flow velocity.	Nov. 2013

Table Z: Deployment site infrastructure and operation of the MAKO turbine (2020c).

Site Infrastructure	Geographical Location
Barge	Sydney, AU Kagoshima, Japan
Bridge	Sentosa, Singapore
Wharf	Port of Gladstone, AU

Table AA: Technology developer companies and description of pilot demonstration projects and projected capacity from now into the future (Sabella, 2020b,c,d,e,f,g,j).

Company	Project Description	Timeframe
Sabella	Experimental (D03) turbine in operating conditions (Brittany, France). Establish basis of technology after 12-month trial. 3m diameter rotor,30 kW rated power, 25 m depth, rest on seabed.	2008
	First grid connected electricity supply (D10 turbine). 10m diameter rotor, 1MW max power output (4m/s), 55m water depth.	2015
	ICE - Sea campaign of D10 turbine. Project to couple energy storage with RE sources for Ushant Island. Synchronize system with tidal in off peak hours. 3-year sea trials & experimentation	2018
	Capul - Supplier for the island of Capul (Philippines) to provide up to 500MW power capacity. First phase is 3MW power plant (3* D18 turbines) combined with onshore battery storage (1 MWh)	2019
	PHARES - Pilot tidal farm and hybrid energy model with 2 D12 turbines at 500 kW each, wind turbine (0.9 MW), PV (500 kW) and energy storage to switch to 80% RE energy mix for the island.	2021
	TIGER: Tidal Stream Industry Energiser Project: - 1MW new turbine capacity in Pembrokeshire - Build energy scheme with 1.2MW capacity at Isle of Wight - Repurpose site in Brittany, install 1000KW of capacity - Reach consenting to install 500kW and potential of additional 6MW for new sites. Total potential output of 8.8MW of additional energy capacity, energy cost reduction, and GHG emissions reduction.	Current

Table AB: Technology developer companies and description of pilot demonstration projects and projected capacity from now into the future (Wave Swell, 2020b,c,d).

Company	Project Description	Timeframe
WaveSwell	Integrate 200 kW wave energy with grid provided hydro, solar and wind at King Island, Tasmania	2019-2020

Annex 13: The following figures and tables display energy consumption and emissions related data to the Ports sector.

Table AC: Total throughput and value of cargo in Australia for the financial year 2018-2019 (Ports Australia, 2020).

	Total throughput (mass tonnes)	Value of Cargo (AU$ millions)
Export	1,466,135,136	20,266,427
Import	150,132,581	6,678,936
Total	-	**57,409,832**

Table AD: Extrapolated energy data per source for four Australian Ports interviewed in TJ (Author's own).

Energy source [TJ]	Brisbane	Esperance	Gladstone	Townsville	Broome
Total Energy	144.2	567.6	916.5	26.0	N/A
Total Electricity	11.5	45.4	73.3	2.1	N/A
Diesel	131.7	518.2	836.7	23.7	N/A
Renewable Energy (solar)	1.4	5.7	9.2	0.3	N/A

Figure K: Example of tidal chart tables for the Port of Broome from the month of January to April – data is recorded for all 12 months of the year 2020 (Marine Science Aus., 2019)

BROOME – WESTERN AUSTRALIA **2020**

LAT 18° 0' S LONG 122° 13' E

Times and Heights of High and Low Waters

Local Time

JANUARY

Day	Time	m	Day	Time	m
1 WE	0139 0803 1409 2017	8.46 2.52 8.15 3.21	16 TH	0144 0817 1417 2036	9.17 1.85 8.91 2.39
2 TH	0211 0833 1443 2048	7.98 2.99 7.80 3.64	17 FR	0226 0854 1459 2119	8.63 2.39 8.54 2.88
3 FR	0247 0905 1522 2126	7.45 3.49 7.43 4.08	18 SA	0312 0935 1547 2211	7.95 3.04 8.07 3.45
4 SA	0331 0945 1611 2221	6.90 4.01 7.07 4.49	19 SU	0409 1026 1651 2329	7.22 3.71 7.59 3.93
5 SU	0440 1047 1724	6.40 4.47 6.83	20 MO	0538 1149 1819	6.66 4.25 7.30
6 MO	0031 0637 1246 1900	4.60 6.23 4.60 6.90	21 TU	0120 0730 1338 1956	3.95 6.58 4.33 7.40
7 TU	0206 0815 1407 2017	4.15 6.56 4.32 7.30	22 WE	0251 0902 1507 2114	3.47 7.02 3.95 7.86
8 WE	0302 0913 1506 2112	3.50 7.09 3.86 7.85	23 TH	0350 0958 1607 2206	2.83 7.62 3.39 8.38
9 TH	0347 0956 1555 2155	2.83 7.64 3.34 8.42	24 FR	0437 1040 1653 2248	2.26 8.16 2.86 8.83
10 FR	0428 1034 1639 2235	2.21 8.16 2.83 8.94	25 SA	0517 1117 1732 2323	1.84 8.57 2.45 9.14
11 SA	0509 1111 1722 2313	1.72 8.59 2.39 9.34	26 SU	0552 1149 1807 2355	1.58 8.85 2.18 9.30
12 SU	0548 1148 1802 2350	1.37 8.92 2.06 9.58	27 MO	0624 1220 1838	1.48 8.99 2.07
13 MO	0627 1224 1842	1.21 9.13 1.88	28 TU	0026 0653 1249 1906	9.31 1.52 9.03 2.08
14 TU	0027 0704 1300 1920	9.65 1.24 9.20 1.86	29 WE	0054 0720 1316 1933	9.19 1.68 8.96 2.22
15 WE	0105 0740 1338 1958	9.51 1.45 9.13 2.04	30 TH	0122 0744 1343 1958	8.96 1.95 8.80 2.45
			31	0149 0808	8.61 2.31

FEBRUARY

Day	Time	m	Day	Time	m
1 SA	0217 0833 1439 2051	8.15 2.77 8.19 3.22	16 SU	0246 0902 1509 2133	8.33 2.68 8.49 3.04
2 SU	0247 0900 1510 2123	7.58 3.33 7.75 3.74	17 MO	0328 0936 1555 2225	7.43 3.57 7.70 3.91
3 MO	0324 0931 1550 2209	6.95 3.95 7.25 4.29	18 TU	0430 1028 1713	6.55 4.46 6.96
4 TU	0421 1022 1700	6.31 4.58 6.80	19 WE	0035 0652 1307 1936	4.45 6.07 4.92 6.75
5 WE	0036 0646 1253 1904	4.62 6.00 4.88 6.74	20 TH	0248 0912 1513 2121	4.05 6.62 4.40 7.34
6 TH	0223 0851 1429 2044	4.14 6.46 4.49 7.23	21 FR	0351 1002 1609 2209	3.29 7.41 3.62 8.05
7 FR	0329 0945 1539 2144	3.39 7.19 3.83 7.97	22 SA	0433 1036 1649 2244	2.59 8.10 2.92 8.66
8 SA	0418 1025 1631 2228	2.60 7.94 3.07 8.72	23 SU	0508 1107 1723 2315	2.03 8.64 2.37 9.10
9 SU	0501 1103 1715 2308	1.86 8.63 2.33 9.36	24 MO	0540 1135 1754 2343	1.64 9.02 1.97 9.37
10 MO	0541 1138 1757 2345	1.27 9.21 1.70 9.82	25 TU	0608 1202 1822	1.42 9.27 1.73
11 TU	0619 1212 1835	0.89 9.63 1.26	26 WE	0010 0635 1226 1848	9.48 1.34 9.39 1.64
12 WE	0020 0654 1246 1911	10.05 0.76 9.87 1.08	27 TH	0036 0659 1250 1912	9.46 1.40 9.41 1.67
13 TH	0056 0728 1321 1946	10.01 0.89 9.89 1.18	28 FR	0100 0721 1313 1935	9.31 1.58 9.33 1.82
14 FR	0132 0800 1355 2020	9.70 1.28 9.65 1.58	29 SA	0125 0742 1337 1958	9.04 1.89 9.11 2.12
15 SA	0208 0831 1431 2055	9.12 1.89 9.17 2.22			

MARCH

Day	Time	m	Day	Time	m
1 SU	0149 0804 1402 2022	8.62 2.33 8.76 2.57	16 MO	0222 0834 1436 2102	8.45 2.65 8.61 2.89
2 MO	0216 0827 1428 2048	8.08 2.91 8.27 3.15	17 TU	0300 0900 1514 2140	7.49 3.62 7.65 3.92
3 TU	0244 0850 1458 2118	7.41 3.58 7.69 3.83	18 WE	0349 0934 1620 2344	6.53 4.62 6.71 4.78
4 WE	0320 0919 1540 2211	6.68 4.32 7.04 4.55	19 TH	0610 1305 1932	5.87 5.26 6.36
5 TH	0439 1029 1736	5.95 5.08 6.48	20 FR	0250 0917 1519 2119	4.36 6.58 4.49 7.11
6 FR	0146 0838 1404 2027	4.58 6.14 4.88 6.85	21 SA	0342 0951 1600 2157	3.56 7.42 3.63 7.90
7 SA	0318 0936 1530 2135	3.75 7.06 4.01 7.78	22 SU	0417 1019 1633 2228	2.83 8.14 2.90 8.54
8 SU	0407 1011 1621 2218	2.79 8.01 3.00 8.71	23 MO	0448 1045 1703 2256	2.24 8.72 2.30 9.01
9 MO	0448 1046 1703 2255	1.90 8.89 2.03 9.49	24 TU	0517 1111 1732 2322	1.81 9.14 1.85 9.32
10 TU	0526 1120 1742 2331	1.17 9.63 1.23 10.04	25 WE	0543 1135 1758 2348	1.54 9.43 1.55 9.48
11 WE	0602 1152 1819	0.70 10.15 0.70	26 TH	0609 1158 1824	1.40 9.60 1.38
12 TH	0005 0636 1224 1854	10.30 0.52 10.42 0.49	27 FR	0012 0632 1221 1847	9.50 1.39 9.67 1.35
13 FR	0038 0707 1256 1926	10.26 0.66 10.40 0.65	28 SA	0036 0654 1243 1910	9.41 1.52 9.61 1.48
14 SA	0112 0737 1329 1958	9.92 1.09 10.08 1.15	29 SU	0100 0716 1306 1933	9.18 1.79 9.41 1.78
15 SU	0147 0806 1402 2029	9.29 1.77 9.46 1.93	30 MO	0125 0738 1331 1957	8.80 2.22 9.05 2.24
			31	0152 0801	8.27 2.79

APRIL

Day	Time	m	Day	Time	m
1 WE	0221 0823 1426 2051	7.62 3.47 7.91 3.58	16 TH	0335 0915 1600 2255	6.60 4.71 6.60 4.78
2 TH	0256 0851 1505 2137	6.88 4.24 7.18 4.38	17 FR	0527 1240 1847	6.02 5.28 6.25
3 FR	0405 0951 1645	6.13 5.04 6.48	18 SA	0215 0848 1457 2050	4.54 6.54 4.53 6.90
4 SA	0104 0801 1342 2001	4.70 6.17 4.93 6.77	19 SU	0312 0921 1535 2128	3.85 7.32 3.73 7.62
5 SU	0253 0909 1512 2113	3.89 7.15 3.92 7.74	20 MO	0347 0949 1606 2159	3.20 8.01 3.02 8.23
6 MO	0343 0946 1600 2157	2.92 8.19 2.80 8.69	21 TU	0417 1015 1635 2228	2.65 8.58 2.43 8.70
7 TU	0424 1021 1642 2234	2.02 9.13 1.77 9.47	22 WE	0446 1040 1703 2256	2.22 9.02 1.95 9.02
8 WE	0502 1054 1721 2310	1.31 9.88 0.97 9.97	23 TH	0513 1105 1729 2322	1.90 9.34 1.60 9.21
9 TH	0538 1126 1757 2344	0.86 10.38 0.48 10.19	24 FR	0539 1128 1755 2348	1.71 9.55 1.38 9.27
10 FR	0612 1158 1831	0.71 10.59 0.35	25 SA	0605 1151 1821	1.64 9.64 1.32
11 SA	0018 0643 1230 1904	10.11 0.87 10.48 0.59	26 SU	0013 0628 1215 1846	9.22 1.71 9.61 1.43
12 SU	0052 0713 1303 1935	9.75 1.30 10.07 1.16	27 MO	0039 0653 1240 1911	9.03 1.93 9.42 1.72
13 MO	0127 0742 1337 2007	9.14 1.98 9.37 1.98	28 TU	0106 0718 1308 1938	8.70 2.32 9.06 2.18
14 TU	0203 0810 1411 2039	8.35 2.83 8.48 2.95	29 WE	0136 0743 1337 2006	8.23 2.85 8.56 2.79
15 WE	0242 0839 1451 2117	7.46 3.77 7.51 3.94	30 TH	0210 0811 1411 2041	7.64 3.49 7.93 3.48

Annex 14: Average emission factors for natural gas and liquid fuels combusted

Natural gas (NG) combusted fuels	emission factor [kg CO2/kWh]	Liquid fuels combusted	Emission factor [kg CO2/kWh]
NG distributed in pipeline	51.4	Crude oil	69.6
LNG	51.4	Other NG liquids	61
Compressed NG	51.4	Diesel oil	69.9
Gaseous fossil fuels	51.4	Fuel oil	73.6
		LPG	60.2
Average NG fuels	**51.4**	**Average liquid fuels**	**66.9**

Annex 15: Illustration of the research methodological approach