PERFORMANCE FEASIBILITY OF A MULTI-SOURCE OFFSHORE RENEWABLE ENERGY PLATFORM FOR AQUACULTURE

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ABSTRACT

The global aquaculture industry is facing new challenges as it strives to satisfy the continually growing demand for seafood products. The expanding industry brings with it challenges such as the diminishing availability of suitable coastal zones due to increased competition for marine-use areas, and a responsibility to limit negative impacts to the environment. As a potential solution to the negate environmental impact and continue industry expansion, operations are expected to transition further offshore. Moving aquaculture operations offshore presents several challenges, foremost of which is the provision of energy. This paper explores the feasibility of using a novel multi-source renewable energy platform to overcome the reliance on diesel in the offshore aquaculture industry. Through the development of a numerical model, this solution proposes a scalable renewable energy platform located off the coast of Tasmania utilising solar photovoltaic (PV), wind turbines and wave energy conversion. The feasibility is assessed through a numerical model based on factors such as resource availability, energy demand and conversion system efficiencies to determine how different design and resource variable influence the ability of the platform to meet the energy requirements.

Keywords: Offshore Renewable Energy, Aquaculture, Co-location, Floating Structure, Numerical Model

NOMENCLATURE

ρ	Density [$^{kg}/_{m^3}$]
f	Frequency [Hz]
g	Gravitational Acceleration [$^{m}/_{s^2}$]
P_C	Total Combined Energy [kWh]
P_d	Energy Demand [kWh]
P_s	Solar Power [$^{kW}/_{m}$]
P_{sd}	Surplus/Deficit Energy [kWh]
P_w	Wave Power [$^{kW}/_{m}$]
P_{wa}	Absorbed Wave Power [kW]

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1. INTRODUCTION

The global aquaculture market was valued at 92.3 billion USD in 2021 and is seeing substantial increases each year, with a projected compound annual growth rate of 9.71% [1]. However, as expansion continues, it bring with it previously unconsidered challenges as a move to deeper waters becomes more inevitable. In Tasmania, the salmon industry brings a billion dollars to the state annually, with the state government supporting a notion to double the production to $2 billion annually through the implementation of a new 10-year industry growth plan commencing in January 2023. The plan aims to achieve growth through government incentives to support aquaculture developments in areas further from shore, with higher energy, increased exposure and deeper waters expecting to increase production potential [2].

The expanding industry brings with it a responsibility to limit negative impacts on the environment, with sustainability being a priority outcome of the industry growth plan. Alongside the intention to increase production, a legislative council committee has recommended steps be taken to limit nearshore aquaculture sites, particularly in biodiverse or sheltered areas. High concentrations of nitrogen, nutrients, and waste from fish farms are believed to be the cause of green algal blooms in Tasmanian waterways, drawing major criticism from environmental groups and the wider community [3].

As a solution to the negative consequences associated with the expanding industry, Australian and Tasmanian governments have agreed to support the implementation of offshore aquaculture off the coast of Tasmania, with the intent of harnessing recent technological improvements and exploring the expected environmental and resource advantages stemming from undertaking aquaculture in deeper waters [4]. Offshore facilities gain access to swifter currents, reducing the accumulation of sediments and waste produced by farm sites, which eliminates many of the safety and environmental criticisms directed at coastal aquaculture sites [5]. Moreover, moving offshore provides huge potential for upscaling operations, and helps to eliminate area use conflicts with other potential user groups such as tourism, shipping, fishing, energy industry and others [6].

Moving aquaculture operations offshore presents several challenges including increased capital risk and transport costs, the necessitation of more robust cages and technology, and new solutions for the provision of power to the sites. Historically, coastal fish farms have been powered largely by diesel generation. The use of diesel as a fuel source has an adverse effect on the environment, with every litre of diesel combusted releasing 2.68 kilograms of carbon dioxide emissions into the atmosphere [7]. To address both power provision and sustainability concerns by overcoming the reliance on diesel, standalone renewable energy power systems are increasingly being considered. Connection to an onshore grid via subsea cable carries a significant cost over large distances (up to $1.9 million/km) [8], consequently independent systems differ from diesel generation in that they must also incorporate an energy storage system to provide a baseline load.

Several factors are hindering the commercialisation of independent offshore power systems, such as the requirement for new technology and design concepts, and consequently greater capital investment. The harsher ocean environment offshore necessitates robust technology for survivability [9], requiring appropriate materials to resist corrosion and extreme wave and wind conditions which can damage the devices and their moorings.

With harsher environments comes larger wind, wave and solar power resources of which Tasmania has an abundance. Wind is the most extensively used form of renewable energy in the offshore environment, as offshore wind conditions are optimal for power generation [10]. Existing wind farms can produce power in the range of hundreds of megawatts, with turbines currently capable of an energy output of up to 15 MW each, and global offshore wind installations totalling 837 GW in 2022 [11]. Wind turbines can either be fixed or floating, and horizontal or vertical axis, depending on water depth, site conditions and performance requirements. Horizontal axis turbines are more commonly used for large scale projects due to their higher efficiency at greater heights. Vertical axis turbines are ideal for small-scale uses, as they have the advantage of producing electrical energy at lower wind speeds, and accommodate for easier maintenance as a result of shorter towers and generators located closer to the ground, removing the need for cranes in the servicing process which would be advantageous in an offshore location.

Several small-scale wind turbines already exist in the Australian market, with the potential to be implemented for offshore use. Small-scale turbines with swept area diameters of up to 5 metres commonly generate power in the range of 500 W to 20 kW, and have a long product lifespan of greater than 20 years.

Australia has vast solar resources, receiving approximately 58 million PJ of radiation each year which is ten thousand times greater than the total energy demand [12]. The utilisation of this resource is continually increasing, with solar power accounting for 10 percent of the country's total electricity generated in 2020-2021 [13]. Solar power conversion systems can be land-based or floating. Floating PV (FPV) systems are becoming increasingly common worldwide since the introduction of the first commercially available FPV system in 2007 [14]. Floating solar systems are easily scalable to suit different applications, with existing installed systems ranging from approximately 4 kW to 40 MW. Several examples exist for aquaculture, such as the Lashto Fish Farm in Haiti [15] and the Novaton Chessboard project in Switzerland [16]. The main disadvantage of solar power is intermittency [17]. However, the supply is highly predictable so intermittency can be mitigated with backup generation or alternative power sources.

Wave energy extraction requires significant wave power density, rendering only two percent of the worlds coastal waters suitable. The potential wave power output in these locations totals 480 GW (4200 TWh/yr), with Australia having some of the worlds best resources. Tasmania notably has some of the greatest wave energy potential, with the total energy in certain south coast regions determined to be more than 1300 TWh/yr, equating to fulfilling Australia's total electricity demand five times over [18]. There are more than 200 wave energy converters worldwide, with the majority still in the development and testing stages, as well as a small number reaching the deployment stage in recent years such as Wave Swell Energy's 200 kW wave energy project on King Island in Tasmania, which uses an oscillating water column device to deliver power into the existing grid.

An oscillating water column (OWC) is one of the first identified methods of wave energy conversion, and by far the most extensively studied and tested due to its reliability and simplicity of design. An OWC device consists of a partially submerged structure with a hollow section underwater which is made to trap a column of air above the inner free surface. The oscillation of the water column then moves the air inside the internal free surface which drives a turbine [19]. OWCs can be deployed in nearshore or isolated shoreline locations [20], integrated into maritime structures such as a breakwater [21, 22], or in floating plants which can include single or multiple OWC devices [23–26]. Survivability is a key field of research for wave energy converters, as it is one of the main factors currently hindering commercial WEC usage. An additional challenge is the levelized cost of wave energy; it is not currently competitive with other renewable energy resources due to the technology readiness level, and is not as widespread or commercially available.

Several examples of hybrid systems are in development, incorporating multiple conversion techniques to facilitate power production in different weather conditions. Pelagic Power has developed the W2Power Wind and wave system, which is a semisubmersible offshore platform combining wind and wave power. The design includes two wind turbines and multiple oscillating body WECs, with a projected power output of 10 MW, including 3.6 MW from each of the turbines and between 2 and 3 MW from the wave energy convertors [27]. Another example of a hybrid system is by Australian company Bombora, who have proposed a 6 MW floating wave and wind energy offshore platform [28], including 2 MW generated by wind and 4 MW by wave, with future larger models expected to generate up to 18 MW. Multi-source renewable energy technology is still new, and the majority of existing systems are still in the testing and development stages.

This project explores the feasibility of the performance of a scalable renewable energy platform in Tasmania's offshore waters to propose an alternative to the current diesel-centric power generation associated with powering aquaculture operations. The conceptual platform design utilises solar PV, wind turbines and wave energy conversion and is entirely self-sufficient; incorporating its own microgrid to distribute the power generated.

Performance feasibility is assessed through the development of a numerical model, providing a comparison between energy demand, characterised by a demand profile based on hourly and monthly demand variances; and available energy supply, based on the available environmental resources at the site. Power surplus and deficit curves demonstrate how effectively demand is satisfied on an annually, seasonally, daily, and hourly level. The model considers conversion system efficiencies, battery storage capacity and state of charge. Outputs of the model return the optimum number of conversion systems based on corresponding overall platform dimensions, allowing for an assessment of the feasibility of powering the site solely with renewable energy sources through multiple design iterations.

2. THEORY

To evaluate the performance feasibility of the hybrid floating renewable energy barge, it was necessary to derive the power availability associated with each energy source at the deployment site. Solar conversion technologies transform sunlight into useable electrical energy primarily using photovoltaic panels (PV), either for immediate use or to be stored in batteries. The power is generated from the movement of electrical charges within the internal electric field of a solar panel cell. The solar power equation is given as:

$$P_s = A \times \gamma \times Q \times PR \tag{1}$$

Where A is the solar PV area, γ is the efficiency as specified by the manufacturer, Q is the measured solar irradiance, and PR is the performance ratio, which is a ratio of the actual and expected energy output.

When estimating the resource potential associated with ocean waves, available energy increases along with the wave period and wave height. Optimum energy harvesting occurs when the converter is at resonance with the incoming waves. The equation for wave power is given by:

$$P_w = \frac{\rho g^2}{64\pi} H^2 T \tag{2}$$

Where H is the significant wave height and T is the wave period.

The power absorbed by the OWC devices deployed on the renewable energy barge is derived as:

$$P_{wa} = P_w \times \tilde{L}_{pc} \times \gamma \times L_o \tag{3}$$

Where P_W is the wave power, L_o is the width of the OWC device, and $\tilde{L}_{PC}$ is the non-dimensional capture width; the width of wavefront containing an equal amount of power to that absorbed by the OWC as found in [22].

Wind turbines use strong winds to rotate blades around a rotor, which in turn causes a generator to spin, creating electrical power. The efficiency of wind power generation is largely correlated to the size and height of the turbine tower and blades. The wind power equation is given as:

$$P_{10m} = \rho \times \pi r^2 \times C_P \times C_f \times v_{10m}^2 \times N_G \times N_B \tag{4}$$

Where r is rotor blade length, C_p is a power coefficient, C_f is the capacity factor, and U_{10} is wind velocity at 10 metres height. N_G is the generator efficiency and N_B is the gearbox efficiency, which govern the power curve as supplied by the turbine manufacturer.

Utilising the power extracted from each of the three available renewable energy resources, the combined power that is utilised for aquaculture operations and battery replenishment can be found as:

$$P_c = P_s + P_{wa} + P_{10m} \tag{5}$$

Finally, the surplus or deficit power can be found as the difference between the power demand and the combined available power:

$$P_{sd} = P_c - P_d \tag{6}$$

3. METHODOLOGY

A numerical model was developed using MATLAB 2022a to investigate how different design and resource variables could influence the energy production of the system. The model is comprised of three main sections: inputs, requirements, and outputs. Inputs included user-defined variables such as platform length and breadth, solar coverage area (expressed as proportion of total topside area) and starting charge of the batteries. Similarly, data from sourced from external databases including conversion system efficiencies, wind turbine power curve based on manufacturers specifications and environmental data from the Bass Strait and Storm Bay locations was also imported into the input stage of the model. The requirements section is comprised of an energy demand assessment and power supply assessment.

The model is programmed to output a series of plots which ultimately demonstrate the ability of the platform to meet the energy demand of the fish farm. The model functions by taking the measured wind, wave and solar availability at each site, before converting the raw data to useable power values using Equations 1-4. The model then reduces the raw values using individual system efficiencies, as well as a plot of wave power absorption over time. After calculating total available power, the model plots total power from each source against the established power requirement. The plot identifies periods of power deficit and surplus, throughout which the battery state of charge is calculated by comparing energy usage to the sum of the battery capacity and power supply. The flow chart in Figure 1 depicts the flow of operation of the numerical model, from the inputs phase to the outputs.

4. MODEL PARAMETERS

4.1 Platform Design

The outputs of the numerical model govern the design of the platform including overall dimensions, required battery capacity and number, and number of OWCs, solar panels and wind turbines. The conceptual platform design is a square barge with two rows of vertical axis wind turbines, a rectangular section of solar panels. OWCs cover two edges of the barge only, to increase efficiency by placing them in the seawards facing direction. OWC

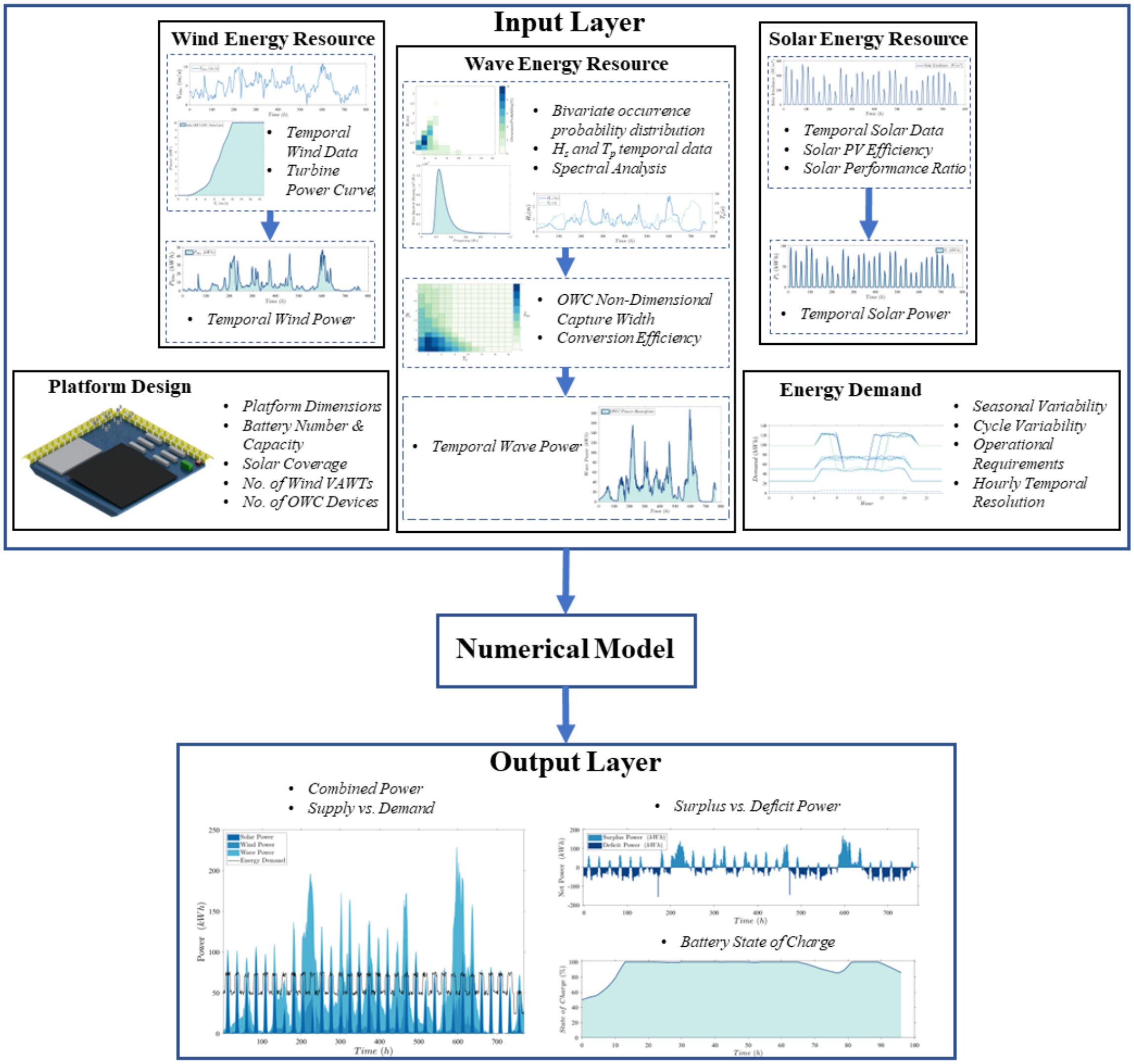


FIGURE 1: A FLOW CHART VISUALISATION OF THE NUMERICAL MODEL PROCESSES, DETAILING THE INPUT AND OUTPUT LAYERS

conversion efficiency was taken as 23% based on current wave to wire efficiencies [29]. An additional design that can be considered is a backwards bent duct buoy, which has an opening in the lee of the wave action. This may result in an increased efficiency to the system, with wave to wire efficiency estimated to be 42% [30, 31].

Sufficient space has been included for storage and emergency systems. Overall dimensions were iterated and refined so that a sufficient percentage of demand is satisfied while also considering the cost of increasing the platform size.

The conceptual design of the barge is shown in Figure 2, with a platform size of 50 x 50 metres and 2 x 1MW batteries; equivalent to approximately one full day of energy supply. Power is distributed via a microgrid, which would have its own series of efficiencies and losses to be considered however that is outside the scope of this investigation.

4.2 Resources

Two different sites are proposed for the project: Storm Bay, and a Bass Strait location approximately 20km from the North Coast. Temporal modelling was conducted for each location, showing the energy inputs/outputs seasonally, monthly, daily and ultimately refining to an hourly basis using time series data to achieve a high-resolution result. The model uses supply and demand power curves to show the fluctuations of the power generation over the course of a day in comparison to the peak demand times.

Temporal modelling was conducted to show the energy inputs and outputs, ultimately down to an hourly level, to demonstrate how effectively the platform can meet the energy demand of the fish farm. Modelling was first based on yearly average data from 2021, before refining down to seasonal, monthly, daily, and hourly to ensure that demand can be met down to this level. The hourly modelling was based on time series data rather than averages to achieve a more high-resolution result. The modelling first considers the total energy available from the wind, wave and solar resources, before reducing this value based on losses due to the efficiencies of the conversion systems, giving a final value for total available power. Supply and demand power curves show the fluctuations of the power generation over the course of a day

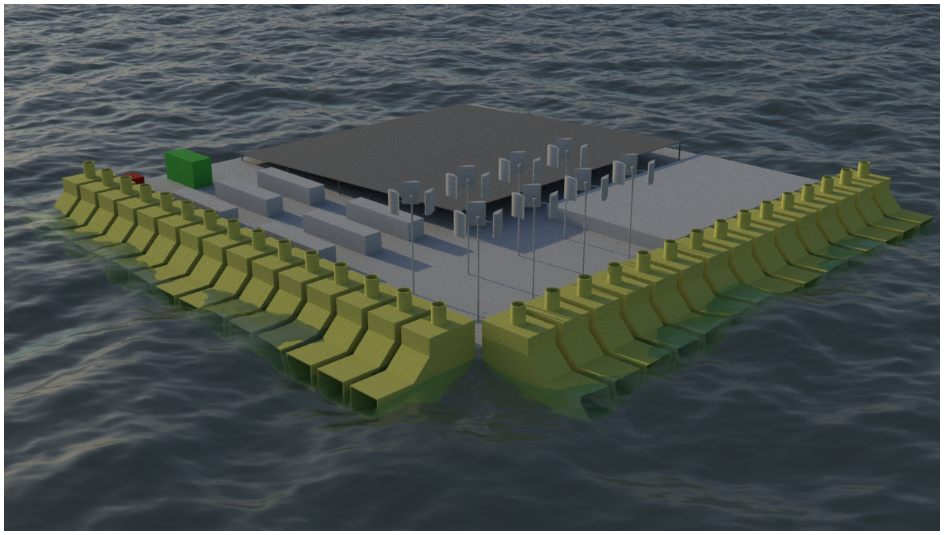


FIGURE 2: RENDER OF THE CONCEPTUAL PLATFORM DESIGN ILLUSTRATING THE OWC DEVICES, VAWTS, SOLAR PV COVERAGE AND ASSOCIATED INFRASTRUCTURE

in comparison to the peak demand times.

4.2.1 Wind and Solar. Hourly time series data for wind speed and solar irradiation was obtained from NASA [32] for 2021. Wind speed was recorded at a height of 10 metres above sea level, and 'all sky' solar data was used, rather than 'clear sky', to account for all weather conditions. Solar panel conversion efficiency was taken as 23.7% based on the Sunpower Maxeon Series CMP22270S [33].This efficiency value is characteristic of most PV systems currently commercially available.

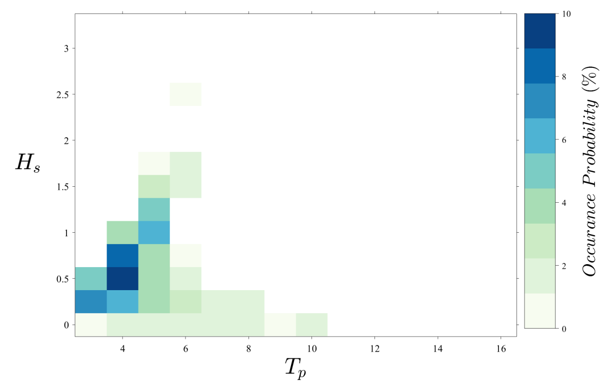
A wind turbine power curve was based on the supplier technical specifications of the selected turbine, the Aelos-V 10kW vertical axis wind turbine [34].

The power curve determines the efficiency of conversion at different wind speeds. By interpolating the power curve, the recorded wind speeds at the two sites were used to determine the wind power produced by the turbine for a given period. The numerical model determines the number of wind turbines that will fit based on spacing requirements, which specify that for optimum performance and limiting shadow effects, turbines must be less than 2 rotor diameters apart widthways and 8 rotor diameters apart lengthways [35].

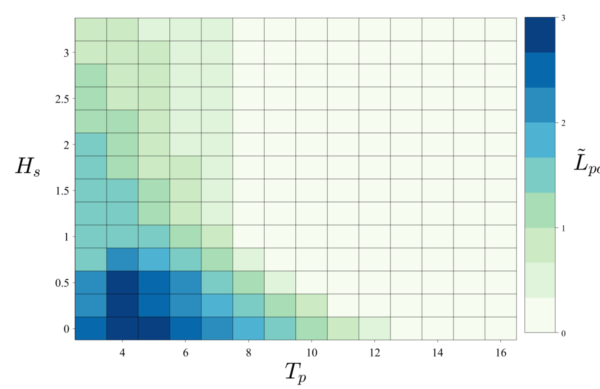
4.2.2 Wave. Time series extract and bivariate probability distribution wave data was obtained from National Map [36]. The time extract wave data was used to find the wave power using Equation 2. The site wave climate considers the bivariate data of various sea spectrums and the probability of their occurrence. The energy content of a wave can be estimated using the Brettschneider spectrum, which is defined as

$$S(f) = \frac{5}{16} H_s^2 f_m^4 f^{-5} \exp\left[-\frac{5}{4}\left(\frac{f}{f_m}\right)^{-4}\right] \tag{7}$$

The bivariate data shows the frequency of occurrence of different wave power values based on the recorded significant wave height and wave energy period values, and was used to determine the OWC wave power absorption based on non-dimensional capture width with respect to the wave height and frequency. An example of the probability of occurrence matrix and OWC non-dimensional capture width matrix can be found in Figures 3a and



(a) Occurance Matrix



(b) OWC Non-Dimensional Capture Width Matrix

FIGURE 3: CORRELATION BETWEEN THE TUNING OF THE OWC DEVICES AND THE MOST FREQUENTLY OCCURRING SEA STATES

Figure 3b respectively.

The non-dimensional capture width is indicative of the mean hydrodynamic power absorption of the devices relative to the incident wave power of crest width equal to the devices width. A derivation of the non-dimensional capture width can be found in [22]. It can be seen that in the model, the OWC devices have been tuned such that the natural frequency of the devices, where resonance occurs, is aligned with the most frequently occurring site-specific sea state. As the sea states shift from the resonant frequency, the OWC devices experience a reduction in performance, which has been captured within the numerical model.

4.3 Batteries

The battery Energy Storage System (BESS) consists of 2 x 1 MWh batteries are included in the model, with each unit having an approximate weight of 27 tonnes and cost of $438,000, based on the Energetech Solar 1 MWh [37]. This capacity amounts to approximately a full day of power requirements to ensure a baseline load is available. The numerical model returns a state of charge as determined by levels of power surplus and deficit. The batteries are modelled as starting at 50% charge, and capped at 0% and 100%. Upon reaching 100% capacity, several different options are available to burn off excess energy, including pumping elements, autonomous desalination by electrolysis or reverse osmosis for provision of a freshwater supply to the fish farm for cleaning processes. In the event of battery depletion due to insufficient renewable energy supply, diesel generators or hydrogen fuel cells could be implemented as backup.

4.4 Aquaculture Power Demand

Demand for the fish farm activities was based on studies conducted through observation of offshore grow-out facilities in Europe [38, 39]. The energy demands were modified to be representative of a 2,500 Head-on-Gutted (HOG) tonne per annum production cycle, which approximates to 500,000 salmon. Similarly, the monthly demands of the were updated to represent aquaculture operations in a southern hemisphere environment. Activities requiring powering include feeding, lighting, bathing, and venturation, and demand varies greatly depending on the number and scale of the fish pens. Power requirements vary over the course of the day, with the current daily demand profile based on a 7am to 7pm feeding period. Monthly and seasonal demand also varies due to different lighting requirements and different salmon life cycle phases. For the purpose of this study, the desalination energy demand was removed from consideration and is only considered as a means to remove excess energy from the system in the numerical model. Demand spikes occur several times a month due to the inclusion of a pump for heavy machinery associated with aquaculture operations. Figure 4 shows the estimated monthly energy demand profiles.

A degree of randomised variability was introduced to the baseline demands to better represent the fluctuations in load experienced during aquaculture operations, which can be observed in Figure 4 for each of the monthly demands. The randomisation was applied to the hourly demand such that no two consecutive days within a month are likely to be identical.

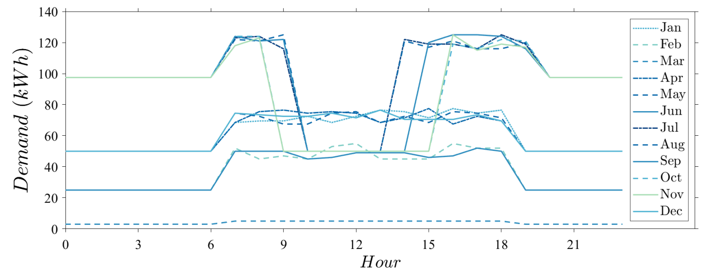
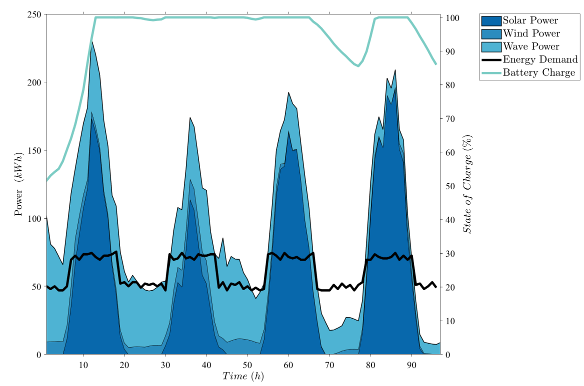


FIGURE 4: MONTHLY DEMAND PROFILES

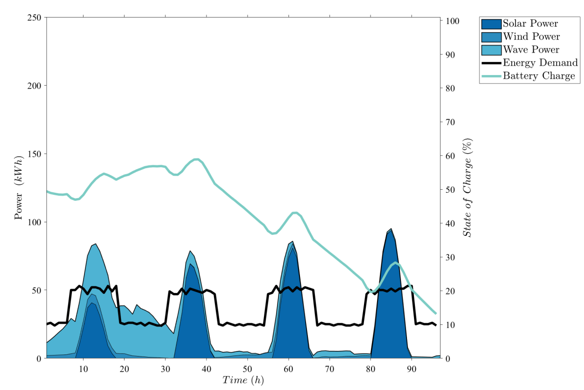
5. RESULTS AND DISCUSSION

5.1 Numerical Modelling Results

Figure 5 shows the energy demand vs supply from each renewable source on a seasonal basis, with a typical 4-day period in the middle of both summer and winter displayed. Figure 5a shows summer, where the intermittency of solar energy supply is clearly demonstrated, with large peaks during daylight hours and no supply overnight.



(a) Summer



(b) Winter

FIGURE 5: SEASONAL VARIABILITY OF THE AVAILABLE ENERGY RESOURCES

The effects of seasonal weather conditions are evident, with significantly higher solar power values experienced in summer, and higher wave power values in the remaining months. In winter (Figure 5b), it can be observed that the lack of solar irradiance

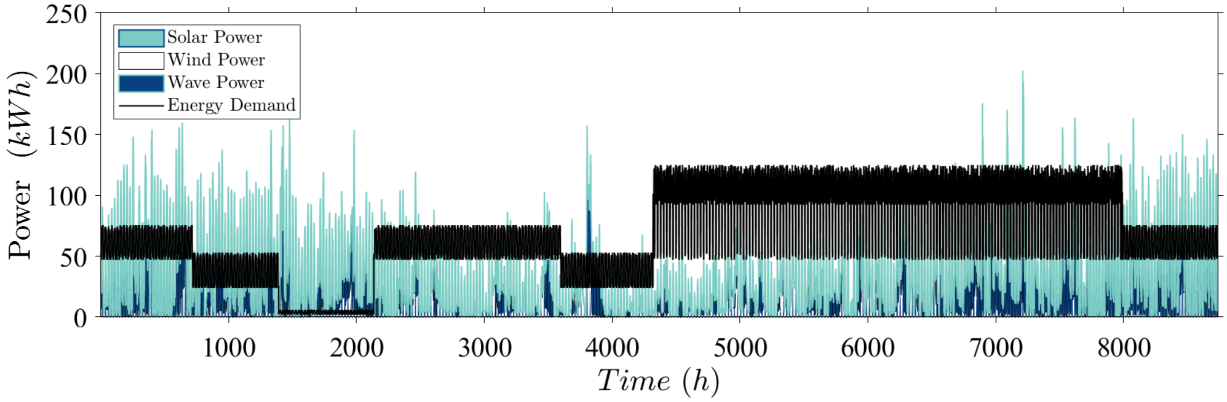


FIGURE 6: YEARLY RENEWABLE ENERGY RESOURCE SHARE VERSUS THE OPERATIONAL ENERGY DEMAND FOR THE BASS STRAIT SITE

during these months can result in demand not being met sufficiently solely off of the renewable resources available.

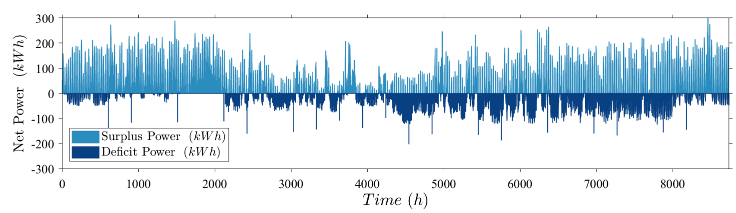
While the wave and wind power during these months is able to supplement the intermittency of the solar supply to a degree, there is a reliance upon the battery storage system to supply power for operations much of the time. While the supply of solar is relatively consistent for each respective season, the supply for wind and wave, which are intrinsically linked, is far less consistent. This is most evident as is illustrated in Figure 5b where little wind or wave energy contribution is evident during the last 3 days, however a storm is experienced on the first day, which provided a much needed increase to the batteries state of charge.

The numerical model is developed to prioritise the utilisation of available renewable energy to satisfy the operational power demand before accessing available energy from the energy storage system. In instances where the available renewable power generation does not meet the operational demand, the required power will be drawn from the batteries, which is clearly demonstrated in Figure 5.

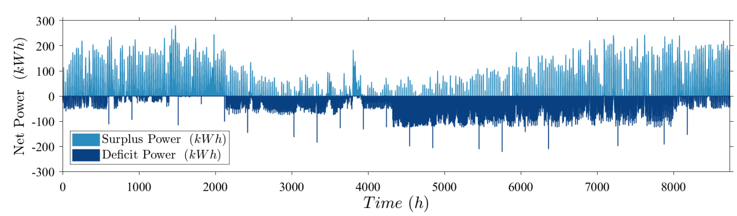
It should be noted that the configuration adopted for the current analysis remained constant throughout all simulations, with approximately 41% of the topside area covered by solar PV panels and a variable number of wind turbines and OWC devices as a function of the overall dimensions of the floating platform. This is not considered an optimal configuration for the design of the platform, nor the share allocation of renewable energy technologies. This configuration optimisation is the topic of ongoing works.

Figure 6 shows yearly demand profile against the power supplied by wind, wave and solar separately for the Bass Straight location. Solar alone has the capacity to supply the fish farm for a large percentage of time during the warmer months, with an appropriate energy storage system, but has a reduced supply in winter. The wind and wave resources are both of similar magnitude, and contribute to the power supply significantly less than solar. The supply has smaller monthly variation in comparison to solar, however the wave power is less substantial towards the end of the year in the warmer months. The figure demonstrates that solar is the most valuable resource in terms of energy supply, followed by wave and then wind.

During the high demand months of July through to November, it is evident in Figure 6 that in many instances there is insufficient supplementary wind and wave energy to compliment the available solar energy in order to fully satisfy demand. This could certainly be modified by adjusting the configuration of the solar PV array, but may also be improved through increasing the operational capacity of the wind turbines to increase production. Similarly, there is potential to improve the power absorption from the OWC devices by modifying the platform sizing and shape to incorporate more seaward facing devices. As the highest demand months for operations lie from mid-winter through to the end of spring, the renewable energy share should be optimised to enhance the energy production capacities of the most abundantly available resources during this period. This would decrease the reliance upon the energy storage system, and also reduce the likelihood that the supplementary diesel or hydrogen system is required.



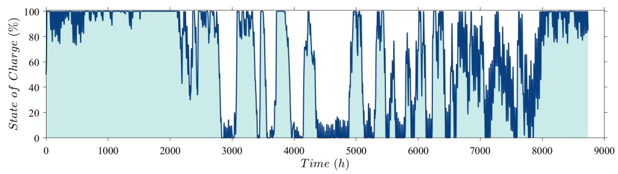
(a) Bass Strait



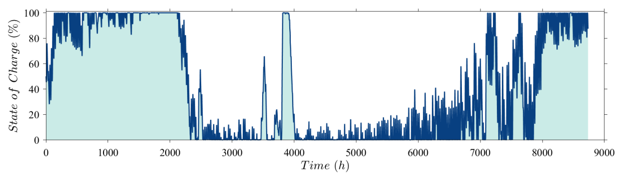
(b) Storm Bay

FIGURE 7: YEARLY POWER SURPLUS AND DEFICIT

Figure 7 show the power surplus and deficit over the course of a year for Bass Strait (Figure 7a) and Storm Bay (Figure 7b) for the combination of energy sources, without considering the supply from stored power in the batteries. In both cases the largest deficit occurs during winter and the beginning of spring due to decreased solar supply and increased energy demand largely due to different lighting requirements. Both sites follow similar seasonal trends, however the Storm Bay site has smaller surplus and deficit levels due to smaller solar energy supply and greater wind and wave supply. While much of the spring and summer months are in power surplus, the cyclic nature of solar means that the overnight supply of power is significantly smaller, leading to overnight periods of deficit however this is mitigated by the addition of battery storage to the model. Wherever possible, power is supplied solely from the renewable sources, and any surplus power is used to charge the batteries. Periods of deficit indicate that there is insufficient renewable resource to meet the demand, causing the battery charge to deplete.



(a) Bass Strait



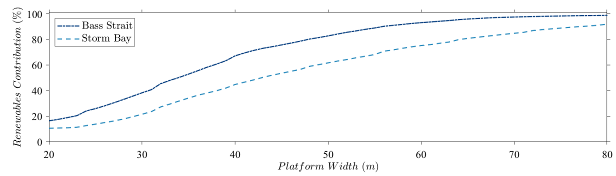
(b) Storm Bay

FIGURE 8: YEARLY STATE OF CHARGE FOR THE ENERGY STORAGE SYSTEM

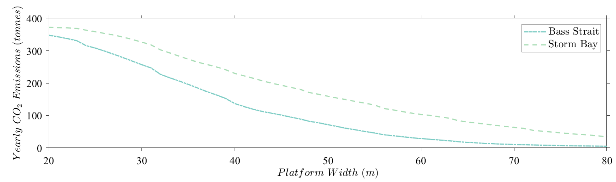
Figure 8 illustrates the annual change in state of charge for the energy storage system comprising of 2×1 MWh batteries. The state of charge reaches zero at multiple instances mainly during winter, correlating to lessened solar supply, where the periods of power surplus are not great enough to charge the batteries sufficiently to meet the heightened power demand experienced in the colder months. During summer, due to increased solar the battery state of charge does not reach zero, meaning the surplus remains at a sufficient level for the platform to fully power the operations during this time. With a barge size of 50 x 50 metres, the numerical model determines that the Bass Strait platform is able to supply the fish farm with power for approximately 82.8% of the year, based on a solar system efficiency of 23.7% and coverage of 41%, and 6 vertical axis wind turbines. A number of instances occur throughout the year-long simulation in which the battery state of charge reaches 0% and there is insufficient renewable power resource available to meet demand. It is in these instances where a supplementary power source, such as diesel or hydrogen as previously mentioned, would need to be utilised to sustain operations. With the same input parameters, the Storm Bay site can power the fish farm for approximately 61.7% of the year.

Multiple design variations were explored to increase the supply of power such as increasing platform size and adding more battery capacity, however there are trade-offs that would come with this such as increased capital cost and weight.

A 500 kW diesel generator consumes fuel at a rate of 100 litres per hour when operating at 3/4 load, and 1 litre of diesel fuel emits 2.68 kg of CO_2 into the atmosphere when combusted. To satisfy the yearly operational demand of the aquaculture farm entirely with diesel, approximately 154500 litres of diesel would be required, equating to 414 tonnes of CO_2 emissions. Figure 9 compares various design iterations of in terms of increasing the platform width, and subsequently length assuming a square platform.



(a) Contribution of renewable energy towards total energy demand



(b) Total Yearly CO_2 Emissions

FIGURE 9: PLATFORM DIMENSION VARIATIONS AND THEIR IMPACT ON RENEWABLE CONTRIBUTION AND CO_2 EMISSIONS

Figure 9 shows that the effect of increasing the platform size lessens exponentially as the size increases, hence loses its additional power supplying benefits when compared to the cost of increasing size. Only the first three considered sizes are viable as there is a substantial difference in the power supply and emissions saved. The effect of adding an extra battery was also explored but was negligible in comparison to the associated cost and weight, with less than 1% increases in power supply annually. This is likely due to the days of no power being consecutive during the winter months, as not enough power is supplied to recharge the batteries for the extra capacity to make a substantial difference.

In comparison to the aforementioned results regarding a 50×50 metre platform, a 30×30 metre platform operating in Bass Strait can contribute supply with renewables for 38.2% of the year, emitting approximately 257 tonnes of CO_2. With the current technology levels, a platform of 75×75 metres is the minimum size that has the capability of supplying the fish farm almost completely with renewable sources, with diesel generation only required for backup and emergencies. However, a platform of this magnitude is not considered to be economically viable for the application.

In the Storm Bay location, a platform 67×67 metres is required to provide an equivalent share of renewable contribution in comparison to the 50×50 metre platform at the Bass Strait site. A platform greater than 80×80 metres would be required to achieve a fully renewable power supply in the Storm Bay site. The performance of the Storm Bay site is inferior due to the reduced supply of solar energy.

The results presented in Figure 9 clearly indicate that the supply of offshore power for aquaculture operations via renewables is not a one-size-fits-all solution. While the configuration utilised in this model was not optimised, the disparity in the results for the two varying sites illustrates the necessity for site-specific solutions based on environmental conditions. Optimisation of renewable energy technologies and platform infrastructure should be a function of the environmental conditions at the site of interest, and a tailored solution could be implemented through the appropriate design and integration of a modular floating system.

5.2 Future Work

Recommended further work includes refining the barge design to a higher level of detail, expanding the range of years of environmental resource data for improved accuracy, and a detailed exploration of methods of using up surplus power once the battery capacity has been reached. It would also be beneficial to explore methods of reducing energy usage for the fish farm operations to lower the energy demand as much as possible. If technology conversion efficiencies improve in future years, increasing the power supply by replacement with higher efficiency devices should be explored. Further modelling should include a microgrid which would have its own series of efficiencies and losses to be considered.

Following further refinements in the numerical modelling to develop more detailed conceptual designs, considerations should be incorporated within the design spiral regarding the economic feasibility of the proposed solution. While outside the scope of the current works, this would have a significant influence design in regards to size and scalability.

As the current design needs to be of a very large scale to fully meet the energy demands, future designs should look towards alternative renewable energy powering arrangements such as colocation with a singular large offshore wind turbine to provide the sole source of power.

6. CONCLUSION

In conclusion this report demonstrates the feasibility of using a novel multi-source renewable energy platform to replace the reliance on diesel in the aquaculture industry. The numerical model determines that while the fish farm can be fully powered by renewable energy sources, the most economic solution is to reduce the size and power the operations with a combination of renewables and diesel generation for the current technology level of conversion systems commercially available. The environmental cost of partially powering with diesel is considered to be justified due to the significant amount of CO_2 emissions that are still saved annually by the system. In the long term, the reduction of emissions and cost saved on fuel assist in justifying the upfront cost associated with implementing a novel system, however the economic viability is uncertain due to significant costs and engineering challenges associated with a platform of large scale.

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