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Assessing Wave Energy Potential and Financial Viability of Oscillating Water Column Systems in North America, with a Focus on California

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Abstract

This paper examines economically efficient wave energy at distinct locations along the Pacific coast of North America, focused on the power output of oscillating water column (OWC) technology devices. Using wave data from 2023, wave energy flux is calculated by applying a 70% efficiency factor, as benchmarked on existing OWC systems. This paper highlights the robust potential of the California coastline, which prompts detailed financial evaluation of OWC viability. Aligned with the United Nations' Sustainable Development Goal 7, this research promotes the economic feasibility of renewable wave energy within the Californian energy portfolio, by analyzing cost projections and potential investment returns.

JEL Codes: P28, Q42.
Keywords: Wave energy, OWC, Sustainability, Levelized Cost of Energy.

Introduction

Harnessing the power of ocean waves, or wave energy power generation, is a significant component in the advancement of renewable energy technology. Wave power can provide an economically cost-effective source of energy as the ocean is the greatest source of renewable energy yet to be exploited efficiently (Doyle and Aggidis, 2019). As opposed to solar or wind, waves tend to be more constant throughout each day, due to gravitational effects, and thus continuous 24-hour electricity generation is feasible using wave energy technologies, versus more familiar renewable methods that remain necessarily intermittent. Indeed the U.S. Energy Information Administration estimates that wave power has the potential to provide more than 60% of the country's energy needs. Among the various technologies designed to capture wave energy, the Oscillating Water Column (OWC) stands out due to its simplicity, efficiency, and effectiveness, which lends itself to a variety of global applications. Moreover, access to coastlines, water courses, and other hydrological systems is generally fairly widely distributed globally, providing an opportunity for a variety of implementations at varying scale to address immediate energy security needs across a plethora of countries. This includes lesser developed countries and more remote islands, where fossil fuels may be absent, and economic growth may be inhibited due to significant energy resource constraints.

Wave energy is thus a potential contributor to energy equity, access and security as highlighted by the United Nations Sustainable Development Goal (SDG) number seven. SDG 7 is one of 17 Sustainable Development Goals established by the United Nations General Assembly back in 2015. It aims to 'ensure access to affordable, reliable, sustainable and modern energy for all'. Wave energy, specifically through adopting technologies like the OWC, may play a pivotal role in diversifying the global energy mix given a heavy continuing reliance on fossil fuels and an increasing marginal cost of adopting renewable technologies in less accessible areas. Indeed, this form of energy has the potential to complement, rather than usurp, other renewable energy sources such as solar and wind, which are by their very nature inherently intermittent. Waves are far more predictable than either the sun or wind energy systems, offering a consistent and reliable form of energy derived from permanent gravitational effects, which allows potentially scalable implementation, a lower whole of life generation risk profile, and higher overall financial returns on initial investment based on such consistencies.

The exploration of renewable energy technologies, especially wave energy through OWC implementation, opens up a further energy frontier intrinsic in any larger view of economics and finance. This approach, while nontraditional, underscores an urgent need to diversify the existing energy portfolio in the face of climate change, energy insecurity, and economic development challenges, given constraints within our fragile ecosystem. However, it is also essential to recognize that the adoption of such technologies is not without its own challenges, including environmental ones.

This paper presents an investigation via data analysis, focused on wave energy potential along the Pacific coastline of North America. Specifically, wave data from four locations situated in Oregon, Washington State, Alaska, and California were analyzed for the year 2023 to assess their viability for implementable pilot OWC systems. The data was sourced from the National Data Buoy Center (NDBC), selecting four buoys after an initial screening of multiple stations. The selection criteria were based on data completeness, proximity to shore and infrastructure, and shoreline adaptability for OWC implementation.

To understand the economic feasibility of wave energy, we evaluated a simulated OWC project through a financial model analysis. For the year 2023, wave data from the selected buoys was examined, with an initial primary focus on wave height and wave period, as these are the key variables needed to calculate Wave Energy Flux with the following formula:

$$WEF[kW/m] = \rho g2(64\pi) - 1 \ HwsTz \approx 0.491Hws2 \ Tz \quad (1)$$

The equation incorporates several key physical parameters: ρ, the density of seawater, which is approximately 1025 kg/m³; g, the acceleration due to gravity, valued at 9.81 m/s²; Hws, representing the wave height in meters; and Tz, the wave period in seconds. Additionally, the formula includes the constant $(64\pi)^{-1}$, which is derived from wave mechanics and serves to simplify the mathematical relationship between these variables, as elucidated by Berastegi et *al.* (2018). Once the wave energy flux was derived, an OWC efficiency factor of 70% was applied to estimate the actual energy transformation potential, based on the performance of existing OWC plants, as referenced in Gayathri et al. (2024).

This analysis was conducted to determine which of the selected locations had the best potential energy output. The focus was on identifying ranges rather than precise values, so we calculated the monthly averages of energy based on hourly wave data. Afterward, the financial analysis was carried out using the location that showed the strongest results. Overall, the data analysis aimed to provide a clear sense of each location's potential and ranges, serving as the basis for supporting our financial assessment.

Data set

Table 1: Monthly averages for the year 2023 Fairhaven, California

Month	Average of WVHT (m)	Average of APD (s)	WEF (kW/m)	"Transformed" Energy Kw/m
Jan	3.3746	9.2033	51.4605	36.0224
Feb	3.4210	9.2577	53.1964	37.2375
Mar	2.4526	7.6369	22.5551	15.7886
Apr	2.060	7.7915	16.2413	11.3689
May	1.9660	7.1640	13.5953	9.5167
Jun	1.9453	6.6815	12.4139	8.6897
Jul	1.4610	6.0734	6.3648	4.4554
Aug	1.3799	6.3524	5.9390	4.1573
Sep	2.2605	7.6932	19.3013	13.5109
Oct	2.4169	8.4850	24.3358	17.0350
Nov	2.4856	8.9870	27.2625	19.0837
Dec	3.8110	10.1090	72.0875	50.4613

For Fairhaven, California, analysis showed a peak energy transformation in December with 72.09 kW/m of wave energy flux and lowest in August of 5.94 kW/m

Figure 1: Monthly variation of transformed wave energy (kW/m) across the year, with the highest value in December (50.5 kW/m) and the lowest in August (4.2 kW/m). Recording the highest energy transformation among all 5 buoys.

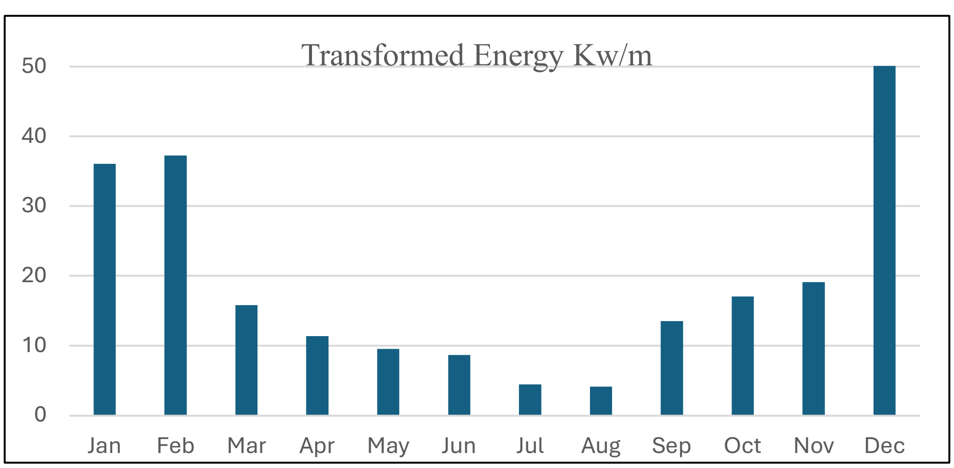

Table 2: Monthly averages for the year 2023 Warrenton, Oregon

Month	Average Wave Height (m)	Average Wave Period (s)	Average kW/m	"Transformed" Energy Kw/m
Jan	2.8225	9.0730	35.4889	24.8423
Feb	2.8544	8.4434	33.7786	23.6450
Mar	1.9985	6.8756	13.4832	9.4382
Apr	2.1687	6.8830	15.8943	11.1260
May	1.4769	7.0182	7.5160	5.2612
Jun	1.3704	6.3907	5.8925	4.1247
Jul	1.0281	5.7717	2.9955	2.0969
Aug	1.1911	6.2519	4.3551	3.0486
Sep	1.9664	7.2704	13.8039	9.6627
Oct	1.8194	7.0988	11.5378	8.0765
Nov	2.2230	7.8800	19.1201	13.3841
Dec	2.9098	8.4142	34.9791	24.4854

For Warrenton, Oregon, January has the peak energy flux at 35.49 kW/m, while July has the lowest value with 2.99 kW/m.

Figure 2: Monthly variation of transformed wave energy (kW/m) across the year, with the highest value in December (24.8 kW/m) and the lowest in July (2.1 kW/m).

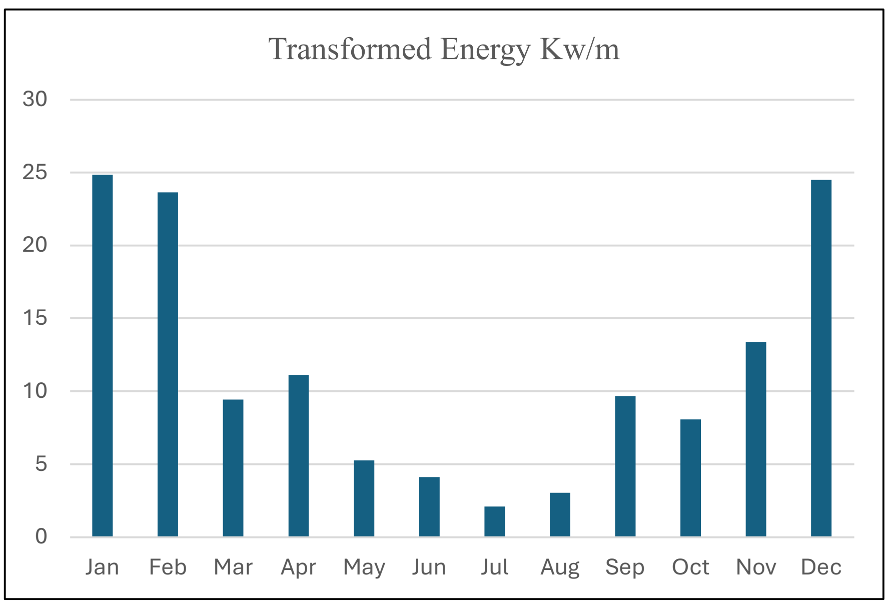

Table 3: Monthly averages for the year 2023 Westport, Washington

Month	Average Wave Height (m)	Average Wave Period (s)	Average kW/m	"Transformed" Energy Kw/m
Jan	9.5074	2.8752	40.2752	28.1926
Feb	8.7946	3.0285	44.2793	30.9955
Mar	7.0382	1.9541	18.8739	13.2117
Apr	7.0949	2.1776	24.6616	17.2631
May	6.8868	1.5230	11.4574	8.0202
Jun	6.5037	1.4234	9.9913	6.9939
Jul	5.7394	1.0424	5.5625	3.8937
Aug	6.3626	1.2309	6.1181	4.2827
Sep	7.4402	2.1174	22.0895	15.4627
Oct	8.0542	2.5331	31.834	22.2838
Nov	8.4975	2.3328	26.9341	18.8539
Dec	8.8135	2.8444	38.6636	27.0645

For Westport, Washington State, the analysis shows February recording the highest wave energy flux at 44.28 kW/m, and July marks the lowest with 5.56 kW/m.

Figure 3: Monthly variation of transformed wave energy (kW/m) across the year, with the highest value in February (31 kW/m) and the lowest in July (3.9 kW/m).

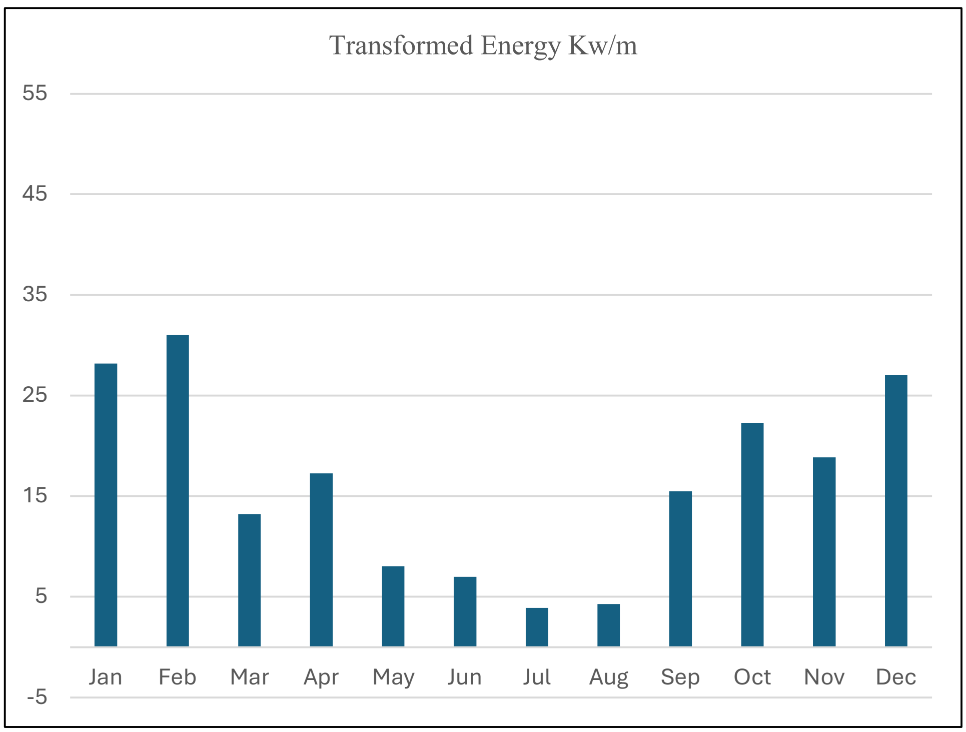

Table 4: Monthly averages for the year 2023 Glacier Bay, Alaska

Month	Average Wave Height (m)	Average Period (sec)	WEF (kW/m)	"Transformed" Energy Kw/m
Jan	2.9505	7.3711	31.9193	22.3435
Feb	2.9275	7.3147	31.4127	21.9889
Mar	2.3126	6.3265	16.6187	11.6331
Apr	2.0588	6.3971	12.7859	8.9501
May	1.7512	6.4651	9.6608	6.7626
Jun	1.524	5.9701	6.6483	4.6538
Jul	0.9761	5.2194	2.4373	1.7061
Aug	1.4494	6.0514	6.2606	4.3824
Sep	2.4923	6.7832	20.8229	14.5760
Oct	2.3484	6.6042	18.0275	12.6193
Nov	3.3186	7.3912	39.9104	27.9373
Dec	3.6578	7.4912	49.3137	34.51959

For Glacier Bay, Alaska, the highest energy output is observed in December with 49.31 kW/m, while the lowest is in July with 2.44 kW/m.

Figure 4: Monthly variation of transformed wave energy (kW/m) across the year, with the highest values in December (34.5 kW/m) and the lowest in July (1.7 kW/m)

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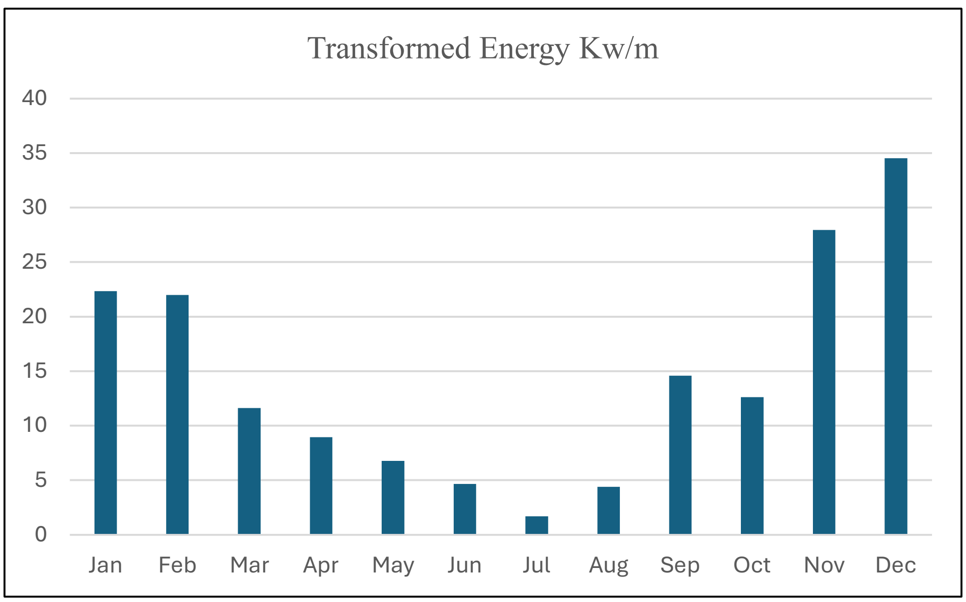
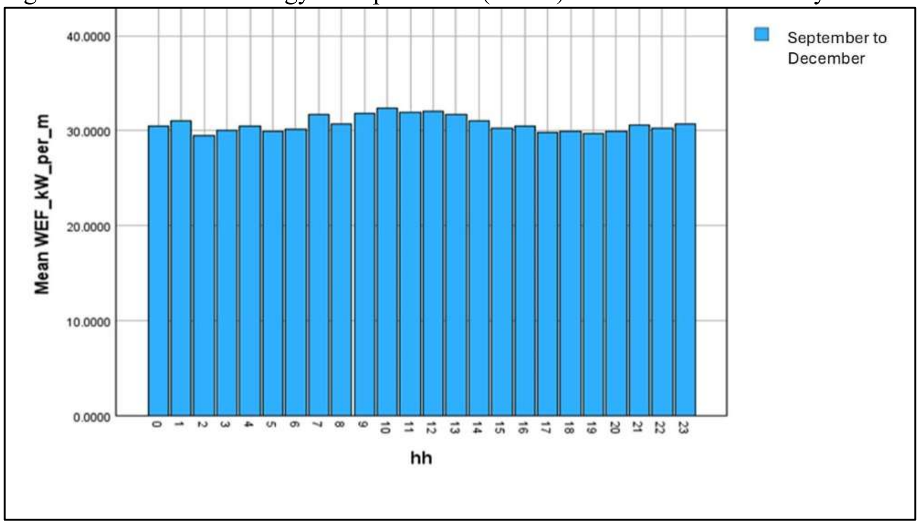


Analysis

Across all locations, the winter months consistently demonstrate the highest WEF, with December emerging as a peak month in multiple regions. For example, Fairhaven exhibits the highest recorded WEF at 72.09 kW/m in December. This trend confirms the impact of seasonal wave intensification along the Pacific coastline, making the winter period critical for maximizing energy generation. Conversely, the summer months experience a sharp decline in wave energy, with July and August typically recording the lowest values across all locations. Glacier Bay, for example, sees a significant drop in WEF to 2.44 kW/m in July, and Fairhaven shows only 5.94 kW/m in August. This decline is consistent across the dataset and highlights the seasonal limitations that any wave energy installation would need to address, likely through energy storage solutions or complementary energy sources such as existing solar arrays that are inherently optimized for production in the summer months, to maintain a stable power supply year-round.

Wave energy potential is backed by its predictability and consistency. To prove this, we ran a multiple linear regression using the SPSS program for the California buoy dataset. That way, we can visualize a histogram by hour:

Figure 5 Mean Wave Energy Flux per meter (in kW) for each hour of the day



The distribution of WEF remains relatively stable throughout the 24-hour period, with only minor fluctuations. This suggests that wave energy is consistently available at all hours, unlike solar power, which is limited to daylight hours, or wind energy, which can be highly variable depending on atmospheric conditions. The regional differences among locations also provide valuable insights. California consistently shows the highest wave energy potential, underscoring its suitability for high-output wave energy systems.

In addition our research in respect of California has particular contemporary relevance given that Governor Gavin Newsom signed Senate Bill 605 Newsom, 2023) to establish the California Energy Commission's role in evaluating the feasibility, costs, and benefits of wave and tidal energy. Unlike wind and solar energy, wave power operates continuously and could help L.A. reach its 100% clean energy goal by 2035. Furthermore the first onshore wave energy project in the U.S. was just launched at the Port of Los Angeles (Smith, 2025) which could potentially scale along the port’s entire breakwater to supply as many as 60,000 households.

Wave energy is still in its early commercial development, and real-world financial assessments remain limited to smaller scale pilots. Energy prices vary depending on the source, influenced by factors such as technology maturity, resource availability, plant capacity, and regional conditions. In California, the Levelized Cost of Energy (LCOE) as define by Corporate Finance Institute (2024) for onshore wind ranges from $24 to $75 per megawatt-hour (MWh), or 2.4 to 7.5 cents per kilowatt-hour (kWh). While utility-scale solar photovoltaic (PV) in the state has an LCOE between $24 and $96 per MWh, equating to 2.4 to 9.6 cents per kWh (DiGangi, 2024).

Wave energy, while still in developmental stages, presents higher initial capital costs. A 2004 study by the Electric Power Research Institute estimated the LCOE for commercial-scale wave energy conversion facilities off the California coast to be between 10 and 11 cents per kWh (Behrens et al., 2008). More recent analyses suggest that with technological advancements, an LCOE of approximately 30 cents per kWh could be achievable within the next decade. (Baca et al., 2022).

This study provides estimates for a simulated single-device pilot project off the coast of San Francisco, California, as well as a full-scale commercial deployment. Using this information, we will conduct an economic analysis of both projects by calculating their Levelized Cost of Energy (LCOE), Net Present Value (NPV), and Internal Rate of Return (IRR) to determine their potential financial viability. The pilot project, consisting of a single OWC device, serves as a testing model before scaling up to a larger installation. The commercial project, on the other hand, represents a full-scale deployment to deliver utility-scale power.

Project Specifications and Financial Assumptions

The financial analysis will be based on data from Appropedia (2024), which provides the specification of these simulated projects. The only values taken from this source were annual energy output, CAPEX, OPEX, and 10-year refit cost; which we used for our calculations. The pilot project consists of a single OWC device located 13 km offshore of San Francisco, with an estimated yearly energy output of 1,131 MWh. The capital cost (CAPEX) is projected at $5,352,000. The commercial-scale project consists of 152 devices arranged in 4 clusters, each producing 1,131 MWh per year, leading to a total capacity of 172.03 MW and a yearly energy production of 172,632 MWh. The commercial site has an estimated capital cost (assuming no scalar efficiencies) of $238,038,000, with an annual operation and maintenance cost (OPEX) of $10,631,000, along with a 10-year refit cost of $14,712,000.

For financial modeling, we assume a project lifespan of 30 years, a discount rate of 8%, and the energy price based on the calculated LCOE.

Table 5: Pilot and Commercial Site projects Costs.

Project Type	Number of Devices	Annual Energy Output (MWh)	CAPEX (USD)	OPEX (Annual) (USD)	10-Year Refit Cost
Pilot Project	1	1,131	$5,352,000	N/A	N/A
Commercial Site	152	172,632	$238,038,000	$10,631,000	$14,712,000

The LCOE represents the cost per unit of electricity produced over the lifetime of the project. It accounts for CAPEX, OPEX, and the total energy generation over 30 years. To calculate the LCOE, we used the following formula as validated by the National Renewable Energy Laboratory (NREL, 2025):

$$\text{LCOE} = \frac{(\text{overnight capital cost} \times \text{capital recovery factor}) + \text{fixed OandM cost}}{8760 \times \text{capacity factor}} + (\text{fuel cost} \times \text{heat rate}) \tag{2}$$

Where: Overnight capital cost is the initial investment to build the plant, CRF is the capital recovery factor, fixed OandM cost covers operation and maintenance independent of output, capacity factor (Ibarra-Berastegi et.al. 2018) is the ratio of the actual energy a power plant produces over a period of time to the maximum possible energy it could have produced if it operated at full capacity the entire time, and fuel cost × heat rate measures fuel expenses per unit of electricity (which we will not use given that there is no cost to fuel in the OWC system)

We are disclosing our calculations for the commercial project, as it involves fewer assumptions and is more accurate in reflecting the overall sense of the investigation. To proceed with the formula, we first need to calculate the Capital Recovery Factor (CRF) (Blank and Tarquin, 2017):

$$\text{CRF} = \frac{r\,(1+r)^n}{(1+r)^n - 1} \tag{3}$$

Where r is the discount rate per period (8%) and n is the number of periods (30 years).

$$\text{CRF} = \frac{0.08\,(1.08)^{30}}{(1.08)^{25} - 1} \approx 0.08883 \tag{4}$$

Since we do not have an actual capacity factor (this is after all a simulation plant), so we substituted it for Annual Energy Output. For the commercial plant:

$$\text{LCOE} = \frac{(238{,}038{,}000 \times 0.08883) + 10{,}631{,}000}{172{,}632} = \$0.188/\text{kWh} \tag{5}$$

We also calculated the Pilot Project's LCOE following the same process; however, we assumed zero OPEX and no refit, given that it is a pilot plant, and the data was not available; the results appear in Table 6 below. Based on the given results, the LCOE analysis reveals that wave energy, as represented by this specific OWC project, remains substantially more costly than established renewable technologies. The pilot project, with a single device, yields an exorbitant LCOE of $0.420 per kWh, a figure attributable to its small scale, where high capital costs are amortized over a minimal energy output, an expected outcome for a demonstration project not designed for economic viability.

Table 6: LCOE results

	Pilot Project ($/kWh)	Commercial Project ($/kWh)
LCOE	0.420	0.188

The commercial-scale project achieves a significantly lower but still high LCOE of $0.188 per kWh. Despite this improvement through economies of scale, this cost is an order of magnitude greater than the current LCOE of mainstream renewables like onshore wind ($0.024–$0.075/kWh) and utility-scale solar PV ($0.024–$0.096/kWh).

According to the U.S. Energy Information Administration (EIA), the most recent national average residential electricity cost to ultimate customers is approximately 17.47 cents per kWh. However, this average rate varies significantly by state, with costs ranging from a low of about 11.42 cents/kWh in Nevada to a high of 40.96 cents/kWh in Hawaii. The average price is still therefore out of reach of the present costs structure of a commercial OWC installation. In California however, one of our specific locales, the average costs of electricity are notably higher at 33.5cc/kWh, which makes a more viable investment case as based on current average electricity pricing.

The next step in the analysis is therefore to evaluate the financial feasibility by calculating the NPV and IRR to determine whether the commercial project is financially viable. Based on the calculated LCOE, we settled on a rounded energy price of $0.20 KW/h which is still less than the industrial rates paid in California for bulk electricity. We calculated NPV both manually and in a Microsoft Excel for completeness. We first determined the total revenue:

Revenue: 172,632,000 kWh * $0.20/kWh = $34,526,400 per year (6)

Then we calculated annual net cash flow, both for a standard year and for every 10th year, where we subtracted the refit cost (in the final period, assuming decommissioning is equivalent to the refit cost. The annual net cash flow equals the annualized revenue less the annual operating expenditures. Net Income in Operating Year (ex Year 10): $34,526,400 - $10,631,000 = $23,895,400. Refurbishment each decade: $34,526,400 - $10,631,000 - $14,712,000 = $9,183,400. Now we calculate the NPV accordingly:

$$\text{NPV} = C_0 + \sum_{t=1}^{n} \frac{CF_t}{(1+r)^t} \quad (7)$$

Where: C_0 is the CAPEX at time 0, CF is the net cash flow at time t, r is the discount rate, and n is the project lifespan. The present value of the 24 identical annual cash flows of $23,895,400 (excluding anomalous Year 10) is calculated using the formula for the present value of an annuity:

$$PV_{annuity} = A \times [\frac{1-(1+r)^{-n}}{r}], \text{ where: } A = \$23{,}895{,}400,\ r = 0.08, \text{ and } n = 30 \quad (8)$$

$$PV_{annuity} = 23{,}895{,}400 \times [\frac{1-(1.08)^{-30}}{0.08}] = 23{,}895{,}400 \times 11.2578 = \$268{,}955{,}000 \quad (9)$$

The present value of the refurbishment (PVR) in Year 10, for example, becomes:

$$PVR10 = \frac{CF_{10}}{(1+r)^{10}} = \frac{14{,}712{,}000}{(1.08)^{10}} = \$6{,}814{,}118 \quad (10)$$

Thus, NPV = - C0 + PVannuity - PVR10 - PVR20 – PVR30 (11)

Hence the NPV = −$238,038,000 + $268,955,000 – $6,814,118 – $3,156,433 – $1,462,039 = $19,538,261 (12)

Regarding the base viability IRR of approximately 9%, this figure warrants a nuanced interpretation. While it exceeds the 8% discount rate, technically classifying the project as profitable under a $0.20/kWh revenue assumption, a 9% return for a project of this scale and risk profile appears exceedingly close to breakeven. Moreover, wave energy remains a nascent, high-risk technology facing significant challenges related to durability in a harsh marine environment and unproven long-term maintenance costs. This result suggests that further cost reductions must be made for such project to become a mainstream attractive alternative.

We therefore also simulated a revenue profile reflecting the average cost of energy in the special case of California in 2025 of 28c/KWh. Table 7 demonstrates the sensitivity of the project's viability to its revenue structure, which is inherent given the high costs associated in the design implementation and approvals required for any such OWC installation.

Table 7: Model Assumptions	*Av. US Electricity/KWh*	*Base Viability /KWh*	*California All Sectors*
CAPEX	($238,038,000)	($238,038,000)	($238,038,000)
Annual Energy Output (KWh)	172,632,000	172,632,000	172,632,000
Retail Price/KWh	$0.175	$0.20	$0.28
Annual OPEX	($10,631,000)	($10,631,000)	($10,631,000)
Refit Cost (10 year cycle)	($14,712,000)	($14,712,000)	($14,712,000)
Project Lifespan in years	30	30	30
Discount Rate	8%	8%	8%
NPV	($29,631,116)	$19,538,261	$175,014,553
IRR	6.614%	8.879%	15.325%

Using data from US Energy Information Administration, (2025) Table 5.3. Average Price of Electricity to Ultimate Customers: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_5_3

The resulting metrics for the Californian state average demonstrated an NPV that surges to $175 million and an IRR that breaks into double digits at 15%, which would transform the project's finances. It shifts from a borderline, high-risk proposition, to a potentially robust and viable investment for the State that could comfortably clear required hurdle rates in the private sector to create significant economic value, whilst importantly reinforcing and diversifying the energy mix of the State.

Conclusion

This study examined the wave energy potential and financial feasibility of Oscillating Water Column (OWC) systems along the Pacific coast of North America, focusing on four distinct locations: Fairhaven, California; Warrenton, Oregon; Westport, Washington; and Glacier Bay, Alaska. By analyzing wave data from 2023, the study calculated Wave Energy Flux (WEF) at each site and assessed their suitability for OWC deployment. The results demonstrated seasonal variations in wave energy availability, with winter months, particularly December and January, showing peak energy production, while summer months exhibited significantly lower wave activity. Fairhaven, California, emerged as the most promising location, consistently recording the highest energy values, making it a strong candidate for future wave energy investment.

The financial analysis leads to a clear conclusion: in its current cost structure, a commercial-scale OWC project is not yet economically viable in general terms. While the model outlines a potential path to profitability through reductions in capital and operational expenditures, the present figures reveal a nascent endeavor close to feasibility but in need of further research and public support . Positive NPV and acceptable IRR outcomes only appear feasible under the most optimistic revenue scenarios, and even then, margins remain too thin to offset the risks of a new technology in a challenging marine environment. However, if technological advances improve efficiency and power output over time, the economic outlook could strengthen considerably. For now, the project’s feasibility cannot be defended solely on financial grounds other than in special case of California. Its success depends not only on market forces but also on policy support, technological breakthroughs that reduce costs, and recognition of its non-financial contributions, such as energy diversification and renewable supply during peak demand.

One further considerable limitation of this analysis is that the data set available only covers the year 2023. Wave behavior can vary significantly across different years and relying on a single year’s data may not capture the broader variability and long-term energy potential of a site. Ultimately, advancing research on wave energy converters is essential. Greater investment in innovation, testing, and optimization could lead to efficiency gains, cost reductions, and improved reliability, allowing projects like these to shift from speculative ventures to viable contributors within a sustainable energy portfolio.

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