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Economics of Future U.S. Wave Energy Markets: A Coupled Analysis of Regional Wave Climate and Energy Market Data

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Abstract

This paper analyzes wave climate and energy market data to produce a regional picture of coastal U.S. wave energy market prices and wave power. Energy production capacity and market cost per kWh trends are established to show prospective energy demand and earning capability for a wave power park in each coastal region. The state data is partitioned amongst the coastal regions: north or south Pacific coast, north or south Atlantic coast, and Gulf coast. Projected earnings data per coastal region is then coupled with the seasonal wave power available in those regions, with the introduction of 'prospective earnings per month per meter of wavefront'. The paper concludes with an economic comparison of power prices, usable wave power between coastal regions, and forecasted renewables demand.

Keywords: North American (U.S.) Wave Power, Wave Climate, Renewables Market, Price per Meter of Wavefront

Nomenclature

H_s = Significant Wave Height (m)
T_d = Dominant Wave Period (s)
P_{wf} = Power per Meter of Wavefront (W/m)
C_{kWh} = Price per kWh (¢/kWh)
e_m = Earnings per Month per Meter of Wavefront ($/m)

1 Introduction

The U.S. western coastal region has more wave energy than the eastern coastal region, and the gulf coast has even less than that. However, wave energy installations on the east or gulf coasts may have higher earning potential due to electricity prices and renewable energy demand. This paper probes the regional availability of wave energy and electricity prices to gauge earning potential in each region. If we assume that the economic supply vs. demand model holds (i.e. supply is directly related to demand), looking at the infiltration of renewable energy in each region enables estimation of future wave energy demand. By pairing this data with the Renewable Portfolio Standard, we can further pinpoint regional wave energy demand.

2 Regional Characterization

Five coastal U.S. regions are analyzed: 1) northwest, 2) southwest, 3) northeast, 4) southeast, and 5) gulf. This study only considers the contiguous U.S., which excludes Hawaii and Alaska. Table 1 lists the states in each coastal region.

Coastal Region	Regional States	
Northwest	• Washington	• Oregon
Southwest	• California	
Northeast	• Maine • Massachusetts • New Hampshire • Rhode Island • Connecticut • New York	• New Jersey • Delaware • Maryland • Washington D.C • Virginia.
Southeast	• North Carolina • South Carolina	• Georgia • Florida
Gulf	• Texas • Louisiana • Mississippi	• Alabama • Florida

Table 1: States Included in Each Coastal Region

3 Wave Climate Characterization

Determining each regional wave climate is the first step in assessing the financial viability of potential wave farms. This section describes how wave climate data was obtained and the results of that data.

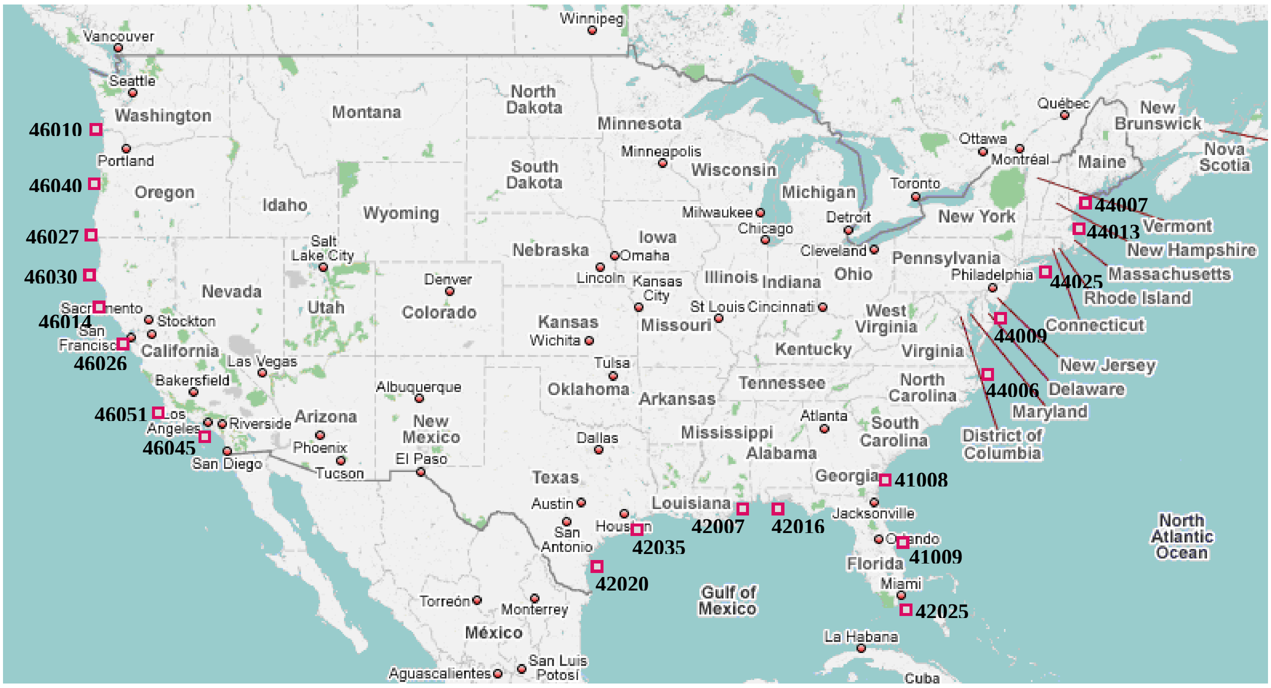

Figure 1: Map of Contiguous U.S. Showing Location and Station Number of Data Buoys Used in Analysis, Backdrop: [4]

Wave Climate Data

The goal in assessing wave climate is to find data spanning several years for each region. A good source of such data is the National Data Buoy Center (NDBC), part of the U.S. Commerce Department's National Oceanic and Atmospheric Administration. The NDBC owns and maintains several data buoys whose data is available to the public [1].

The buoys used for this study were chosen based on their proximity to shore and on the quality and content of their historical data. Accordingly, the selected buoys provide a quality near-shore sampling of significant wave height and dominant wave period. Fig. 1 shows the locations and station numbers of these data buoys while Table 2 indicates which data buoys are grouped in each region.

Coastal Region	Data Buoy Identification Numbers			
Northwest	46010	46027	46040	
Southwest	46014 46045	46026	46030	46051
Northeast	44007	44009	44013	44025
Southeast	41008 44006	41009	42025	
Gulf	42007	42016	42020	42035

Table 2: Data Buoys Included in Each Coastal Region

Power per Meter of Wavefront

Measuring power per meter of wavefront in ocean waves is an inexact science given their irregular nature. Equation (1) is a good approximation if the seastate can be represented by a Bretshneider spectrum [2, 3], and since all of the regions analyzed have a long fetch (the distance travelled by waves with no obstruction), this approximation is valid.

$$P_{wf} \cong 0.42 H_s^2 T_d \qquad (1)$$

As equation (1) demonstrates, locations with long wave periods and large wave heights, such as the west coast, have stronger wave climates. By placing monthly averaged H_s and T_d data from the NDBC into this equation, we obtain the average yearly wave climate per region (Fig. 2). Each region's graphical color code is marked in Table 3. These color codes will be used throughout the paper.

Two interesting facts can be deduced from Fig. 2. Firstly, the west coast has more wave energy than both the east coast and the gulf. Secondly, the east and gulf coasts do not experience as much seasonal wave power variation when compared to the west coast. Such seasonal variation may prove troublesome and should be accounted for by power distribution planners and dsf energy generators.

Coastal Region	Graphical Representation
Northwest	
Southwest	
Northeast	
Southeast	
Gulf	

Table 3: Graphical Representation of Each Region, Used in Figs. 2-7.

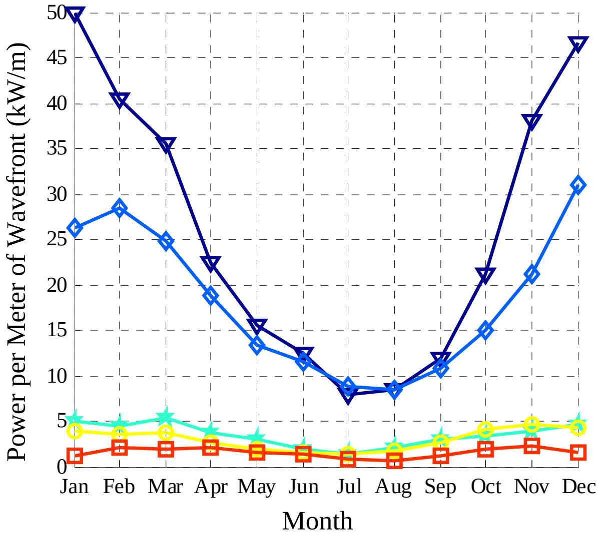

Figure 2: Average Monthly Power per Meter of Wavefront.

4 Regional Electricity Prices

Regional electricity prices may be derived from data collected by the Energy Information Agency (EIA), whose role in the U.S. Department of Energy is to maintain official U.S. government energy statistics. Data from past and present EIA-861 Annual Electric Power Industry Reports were used to obtain historical data on average electricity prices by state [5].

Since EIA-861 historical figures are represented in 'nominal dollars' (not inflation adjusted), it is necessary to convert them into 'real dollars' (inflation adjusted) for proper comparison. To do so, we use the Consumer Price Index (CPI) adjustment. This allows us to convert the value of a previous year's dollar into present day dollars, thus correcting for inflation. CPI data is maintained by the U.S. Labor Department's Bureau of Labor Statistics [6].

When all of this is accounted for, we obtain average historical energy prices in 2008 Dollars (Fig. 3).

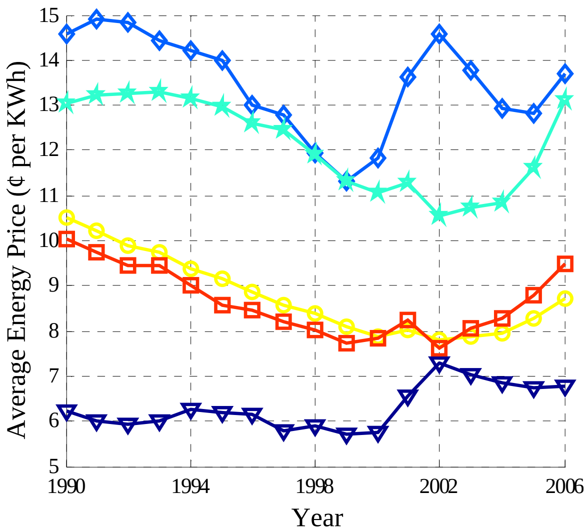

Figure 3: Average Energy Price in 2008 Dollars.

Fig. 3 shows us that the overall average real energy price per region has remained relatively stable, although the southwest and northeast have experienced some instability. It is also evident that the southwest and northeast have the highest prices and the northwest the lowest.

Lower prices in the northwest are primarily due to the abundance of hydroelectric power in the region. Conversely, the sizeable population densities of the southwest and northeast lend themselves to higher prices.

5 Potential Earnings per Meter of Wavefront

By pairing data from Figs. 2 and 3, we can calculate the potential monthly earnings per meter of wavefront per region as in equation (2). This data is illustrated in Fig. 4.

$$e_m = (\text{hours per month}) \times C_{kWh} P_{wf} \tag{2}$$

The following points are worth noting:

- While the northwest has the lowest electricity prices, its enormous wave power gives it large earnings potential, second only to the southwest.
- The southwest has two to five times the amount of earnings potential than the east and gulf coasts.
- Overall, the earnings potential on the west coast far exceeds that of the east and gulf coasts during the winter but is comparable during the summer.

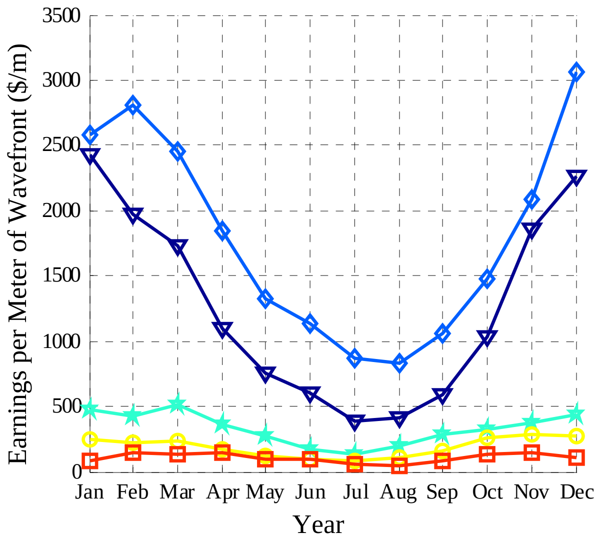

Figure 4: Potential Monthly Earnings per Meter of Wavefront in 2008 Dollars.

6 Regional Renewable Energy Capacity and Generation

This section focuses both on renewable energy capacity and generation per region. Capacity is the amount of energy installed, but this leaves out information about capacity factor (percent of full capacity that is actually utilized). For this reason, generation per region is also presented, thus revealing the amount of renewable energy generated from the installed capacity. Historical trends in this data should correlate with the demand for renewables (e.g. wave energy) in each region.

As with the regional electricity prices, regional renewable energy demand may be derived from data provided by the EIA. To acquire historical data on nameplate capacity by energy source and state, we use data from past and present EIA-860 Annual Electric Generator Reports [7]. Data on generation by energy source and state can likewise be found in the EIA-906 Annual Electric Utility Report [8].

Renewables Capacity and Generation

Neglecting hydroelectric power which is biased towards the northwest, but instead focusing on the EIA-860's "Other Renewables" category, we obtain the graph of nameplate capacity in Fig. 5. This data includes wind, biomass, geothermal, and solar power but not hydroelectric. The same method was applied to the EIA-906 data, yielding a historical account of renewables generation in Fig. 6.

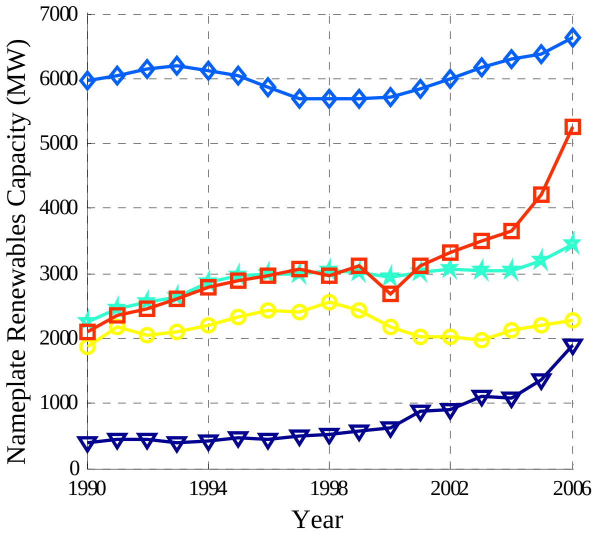

Figure 5: Nameplate Renewables Capacity.

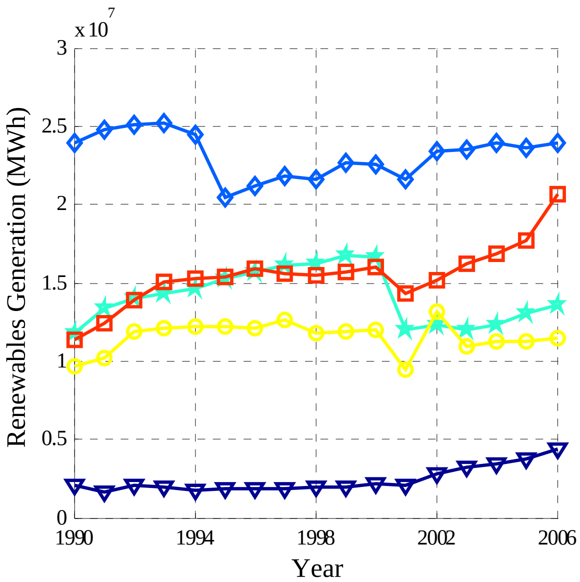

Figure 6: Renewables Generation.

From Figs. 5 and 6, we see that renewables capacity has been increasing in all regions during the past decade, yet generation has not always kept pace except in the gulf, the northeast, and the northwest. The gulf coast has seen the largest increase because of wind energy present in Texas.

7 Regional Renewable Energy Demand

Section 6 confirms that renewable capacity has been increasing over the past decade, indicating that consumer demand for renewables is increasing. Another factor that will play a role in future wave energy demand is the Renewable Portfolio Standard (RPS). The RPS is a policy instituted regionally that requires energy retailers to supply a minimum percentage or amount of electricity from renewables [9]. This section compares the actual percentage of renewables generation to the stated RPS goals of each region, exposing regions where wave energy will have the most demand.

Percent of Total Generation as Renewables

It is best to look at renewables as a percent of total generation as opposed to capacity because renewable energy goals such as the RPS concentrate on actual generation rather than installed capacity. Historical data on energy generation is again taken from EIA-906 to produce the graph in Fig. 7, but hydroelectric generation is also included for a fair comparison with the RPS. From Fig. 7, it is clear that the increase in renewables generation is negligible when compared to total generation, and there does not appear to be any infiltration of renewables into the market. Instead, renewables generation has simply kept pace with total generation.

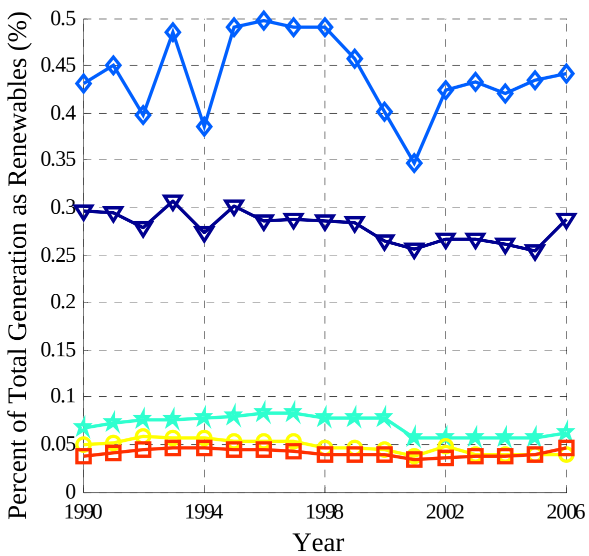

Figure 7: Percent of Total Generation as Renewables.

Renewable Portfolio Standards

Despite stagnation of renewables as a percentage of the energy market (see Fig. 7), Fig. 8 strongly suggests that this percentage will increase in the coming years.

Based on these RPS goals, we can make a few conclusions:

- There will be a considerable increase in demand for renewables in the near future given the magnitude of the RPS goals in contrast with the actual percent of renewables generation (Fig. 7).
- Both the west coast and the northeast have substantial RPS goals that will help spark wave energy development.
- The gulf and the southeast have little to no RPS goals which may prove unaccommodating to wave energy development.

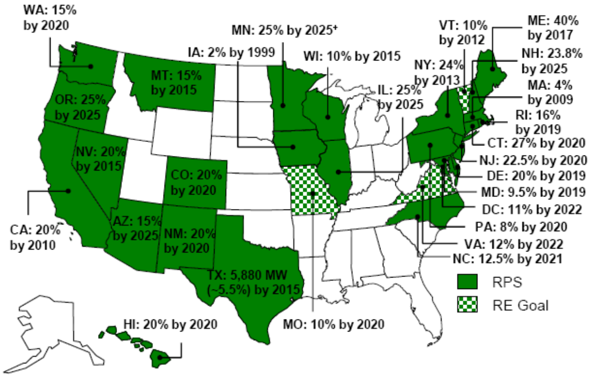

Figure 8: RPS Goals by State [10]

8 Conclusion: Economic Discussion of Renewables Demand vs. Potential Earnings

It is apparent from Fig. 4 that the west coast leads the nation in potential earnings per meter of wavefront and that returns in the summer months are low for all regions. The northeast comes in a close third after the west coast during the summer months, however earnings potential for the northeast is similar to the southeast and gulf with low returns year-round. Additionally, Section 7 reveals that both the west and northeast have aggressive RPS goals, which will yield an inviting market for wave energy developers. With these results in mind, it's safe to say that the wave energy market will expand most on the west coast and the northeast as market conditions exist to promote their growth.

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