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FEASIBILITY STUDY FOR THE USE OF LARGE WINDPOWER GENERATORS IN PUERTO RICO

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I Introduction

With the perspective of continuing rising fuel costs, attention has been focussed once more on the windpower systems of yesteryear. Large 1.5 megawatt turbines are being developed for application in electric power grids. By integrating these systems within a fossil-fuel powerplant network an inexpensive method is achieved for storing and regulating the intermittent and variable output (due to the variation of the wind) that the wind turbines produce. To store the energy from the wind turbines, generation at the powerplants would be reduced an amount equal to the wind power generation. Thus, the fuel that would have been used by the thermoelectric powerplants can be stored for later use. The loads that would have been served by the fossil fuel plants will be served by the energy provided by the wind turbines. This scheme is similar to that being planned for Sweden (1-4) and for the Colorado River Storage Project in the Western United States (5).

The Puerto Rico Water Resources Authority (PRWRA) operates an extensive transmission system in the island of Puerto Rico. Wind turbines could be installed at sites with high windpower potential and linked to a branch of the network. In this way, the energy storage capability of the thermoelectric facilities can be used even if the wind turbines are not colocated with them.

Large wind turbines are being designed, built and tested by the General Electric Company under contract with ERDA and NASA. These are 1.5 megawatt, 61.9m-diameter units. It is expected that production units of this size will be available commercially in the very near future. The cost of the initial production wind turbines is anticipated to be very high until full mass production is achieved. However, as more units are acquired by different utilities and production costs decrease in one hand, and as fossil fuel prices keep climbing as foreseen, a competitive or breakeven point is expected to be reached.

A study has been made of the feasibility of integrating large windpower generators to the existing PRWRA thermoelectric network in Puerto Rico. The findings of that study are presented in this appendix. Preliminary assesments of windpower, windturbine performance, and costs have been made.

II Windpower assessment

1. Wind Climatology

The island of Puerto Rico lies in the zone of the Trade Winds. This is one of the most persistent wind regimes of the world, (6). However, as these northeasterly winds flow over Puerto Rico, they are modified by the topography of the island and by the sea-land breeze. This breeze is established by the temperature gradient between land and ocean. These two effects can act to increase or decrease the speed of the the Trades in regular diurnal and regional patterns.

During the day, the land heats up while the ocean remains basically at the same temperature. The resulting temperature gradient between land and ocean is further emphasized by the fact that a good portion of the heating occurs at heights of up to 3,000 feet due to the interior (mostly east-west) mountain ranges. As the temperature gradient develops, an inland acceleration of the wind occurs.

In the north coast of the island, this acceleration is directed from north to south adding to the strength of the prevailing northeasterly Trades. Fig. 1 schematically portrays this effect. Contrarywise, the thermal acceleration in the south coast is directed from south to north, reducing the strength of the Trades and converting them to south easterlies.

The east coast of the island suffers an easterly thermal acceleration which can increase considerably the strength of the Trades. The west coast, however, experiences a westerly thermal acceleration which opposes the north easterly Trades and sometimes reverses them into westerlies. The resulting winds can be very slow.

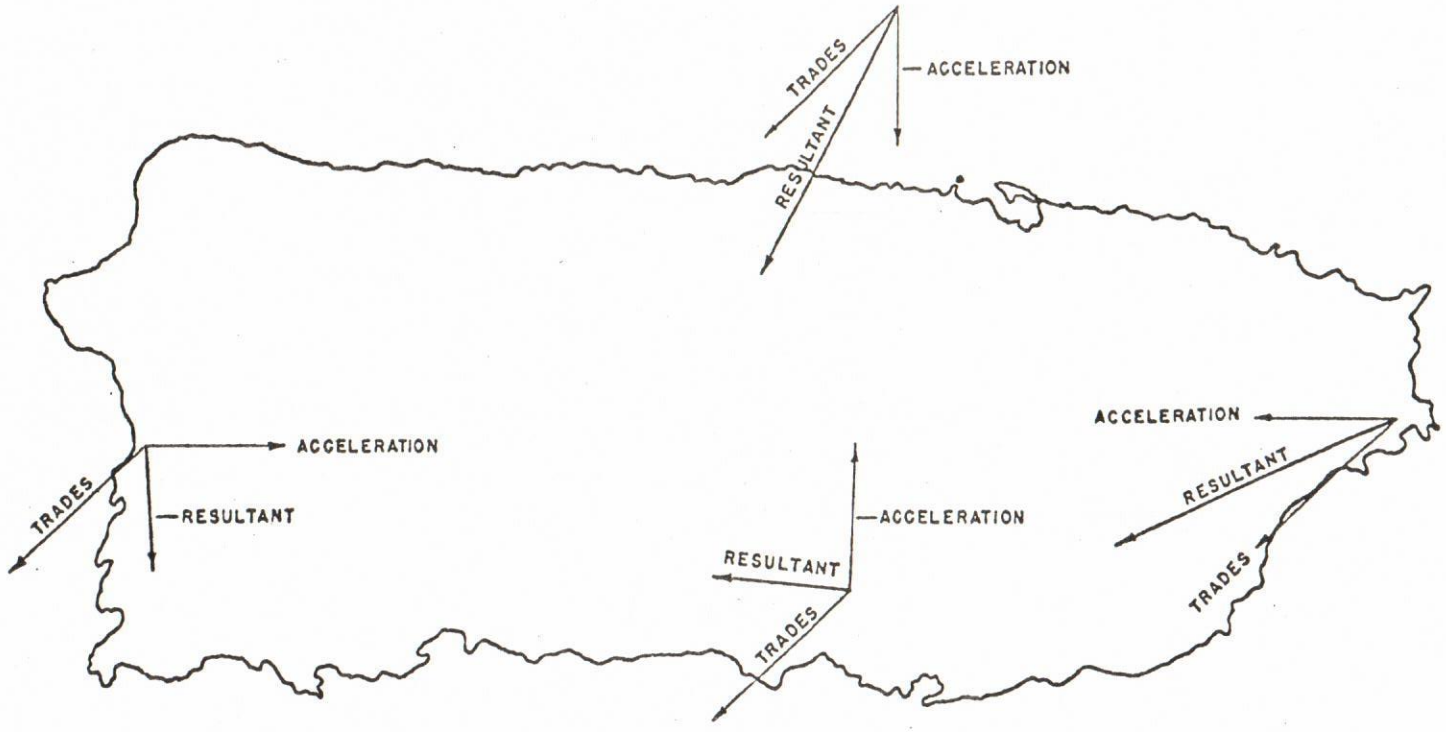

Fig. 1. Schematic representation of the effects of the sea breeze on the trade winds during daytime.

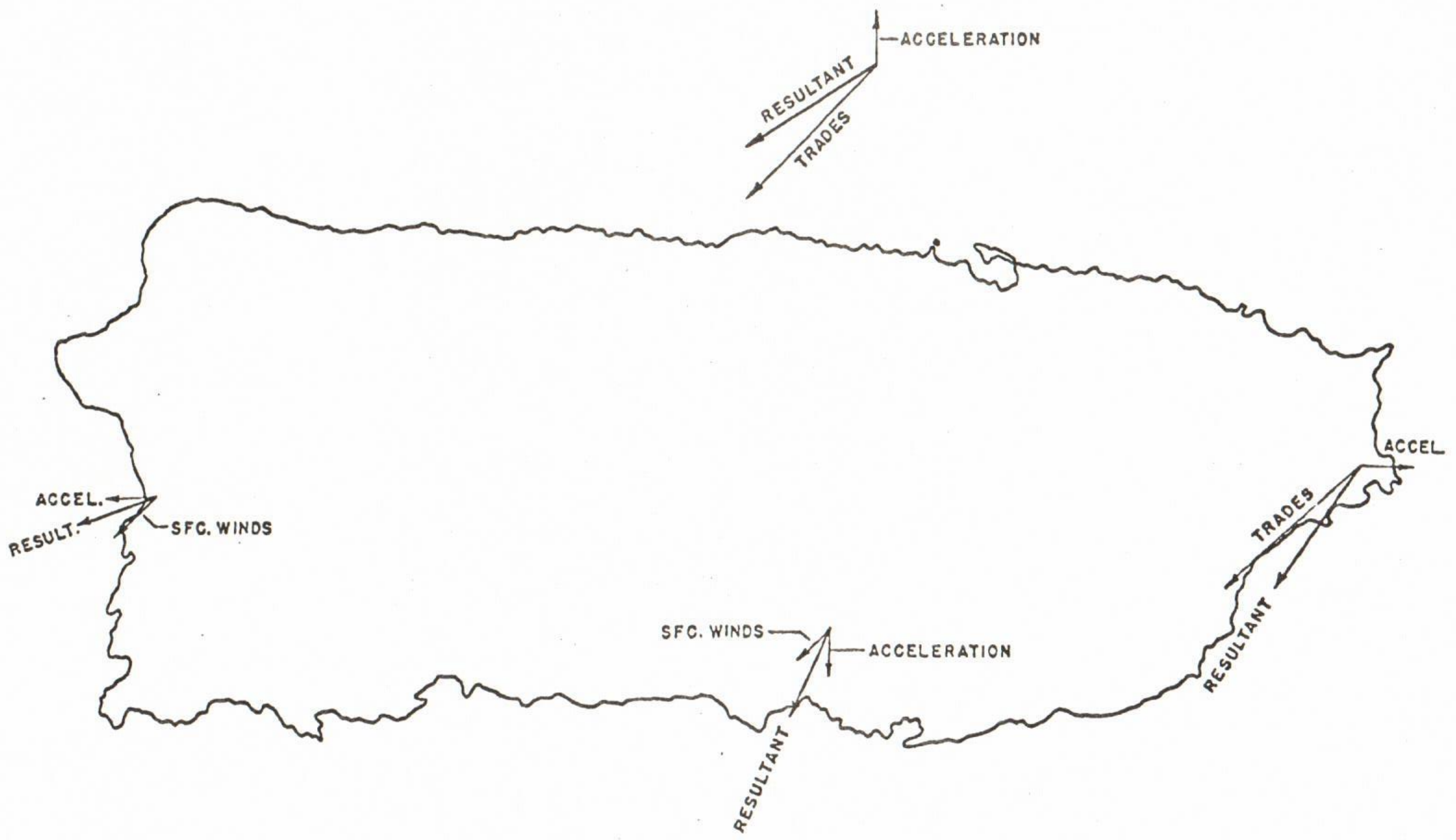

Fig. 2. Schematic representation of the effects of the land breeze on the trade wind during nighttime.

During the night, the land cools off relative to the ocean, and the thermal acceleration is directed toward the ocean. This acceleration is much weaker than the daytime one. The effect of this nocturnal acceleration is shown in Fig. 2. As the Trades flow inland at the north and east coast they are opposed by this acceleration. Although the wind over the land is not as strong as over the ocean, still a good breeze is present due to the generally weak thermal gradient established. During the night, the thermal stability of the low layers of the atmosphere increases. This curtails the vertical exchange of momentum between the surface of the island and the Trades flowing over the south and west coasts from the north east. The wind basically dies down and is sustained only by the weak seaward acceleration that is established during the night and early morning.

Thus, climatologically one would expect the highest potential for wind power utilization in the north and east coasts, as both during the day and night the wind is higher in these regions. Figs. 1 and 2 are, of course, schematic of the effects of the sea-land breeze on the wind power potential in Puerto Rico. Specific details of these effects depend on the particular topographic configuration of the region, the season and the time of the day. These maps, however, provide a guide for the analysis of the limited wind data available and the extrapolation of the analyses to data-void regions.

2. Diurnal oscillation of the wind speed and the corresponding power at selected stations

Fig. 3 prtrays the variation of the speed of the wind with the time of the day at representative stations in the north, south and east coasts of Puerto Rico. The locations of these and other stations are indicated in Fig. 4. These values correspond to the standard anemometer height of 10 meters. As expected, San Juan in the north coast experiences the strongest winds. A maximum of 17

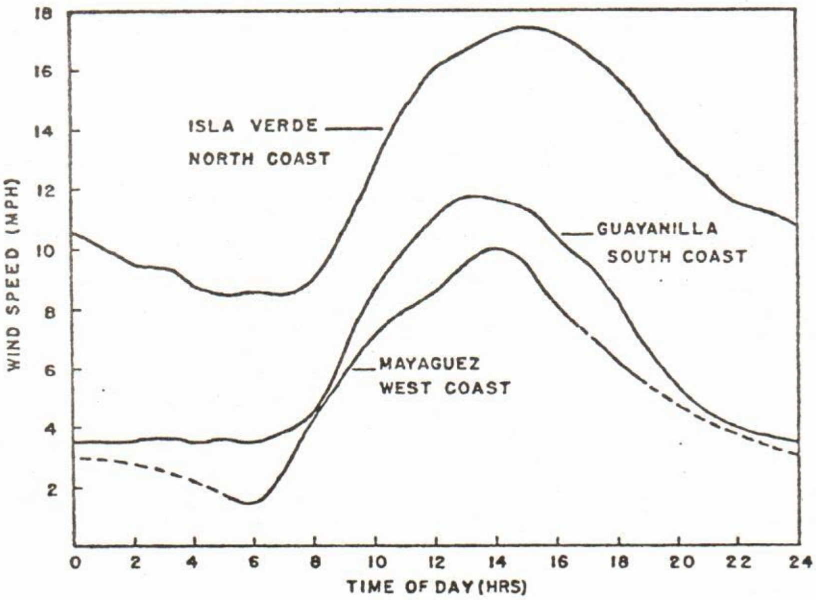

Fig. 3. Diurnal oscillation of the wind speed at selected stations. No actual observations were recorded at Mayagüez during the night and early morning hours. All values correspond to a height of 10 meters.

mph is observed at 3 P.M. when the Trades are reinforced the greatest by the thermal acceleration produced by the daytime temperature gradient between land and water. The weakest winds (9 mph) occur just before sunrise when the reversed land-water temperature gradient becomes largest. The winds at Guayanilla in the south coast are highest (12 mph) at 1 P.M. but are much lower than at San Juan. Nighttime wind speeds are very low (around 4 mph). Mayaguez in the west coast shows the weakest winds of all three stations with a maximum of only 10 mph at 2 P.M. and a minimum of 2 mph before sunrise. A diurnal summary for a station in the east coast is not readily available.

The differences in the patterns of these diurnal variations in wind speed are reflected in the values of the average wind power density for each of the stations. Table 1 presents the average wind power density in a vertical plane perpendicular to the wind direction (watts/m^2) during a typical day for the stations mentioned above.

These values were obtained from

$$p = \frac{1}{2}\rho v^3 \qquad (1)$$

where p is the power density, ρ the air density at anemometer height, and v is the wind speed. This formula was applied to the wind speeds shown in Fig. 3 and an average value obtained for the day. The power density for Roosevelt Roads in the east coast was obtained from a 5 point yearly windspeed frequency distribution.

The north and east coasts have the largest power densities (122.5 and 93.0 w/m^2) with the south and the west coasts having much lower values (25.1 and 13.5 w/m^2). The wind power at Mayagüez is extremely low.

Table 1. Average wind power density in a vertical plane perpendicular to the wind direction (watts/m^2) during a typical day at selected stations in Puerto Rico. Values correspond to an anemometer height of 10 meters.

North Coast	
Isla Verde	122.5
East Coast	
Roosevelt Roads	93.0
South Coast	
Guayanilla	25.1
West Coast	
Mayagüez	13.5

The differences between stations in wind power density seem much larger than the differences in the patterns of diurnal wind speed variation. The reason for this effect is that the cube in Equation 1 amplifies seemingly small differences in wind speed when computing power density.

The different diurnal wind speed patterns produce very different frequency distributions of wind speed during the year. Fig. 5 shows frequency distributions for the four stations considered so far. It can be noticed that as one moves from the west coast to the south, and from the north to the east coasts the maximum frequency occurs at higher wind speeds. Thus, the maximum frequency for Mayagüez corresponds to 0-4 mph, for Guayanilla 4-8 mph, for Isla Verde 4-8 mph also but at a much larger frequency, and 8-12 mph for Roosevelt Roads.

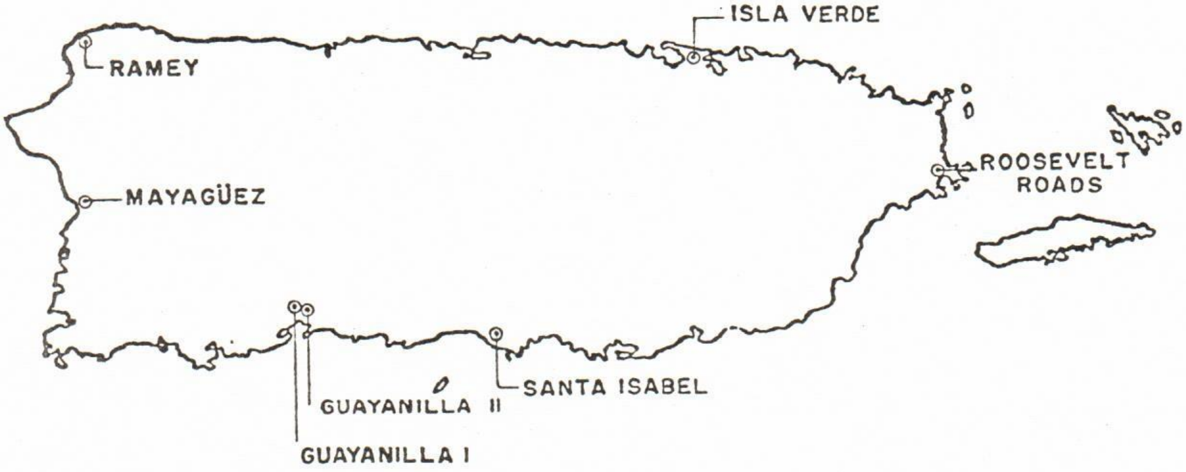

Fig. 4. Map of Puerto Rico indicating the locations of meteorological stations for which wind data is available.

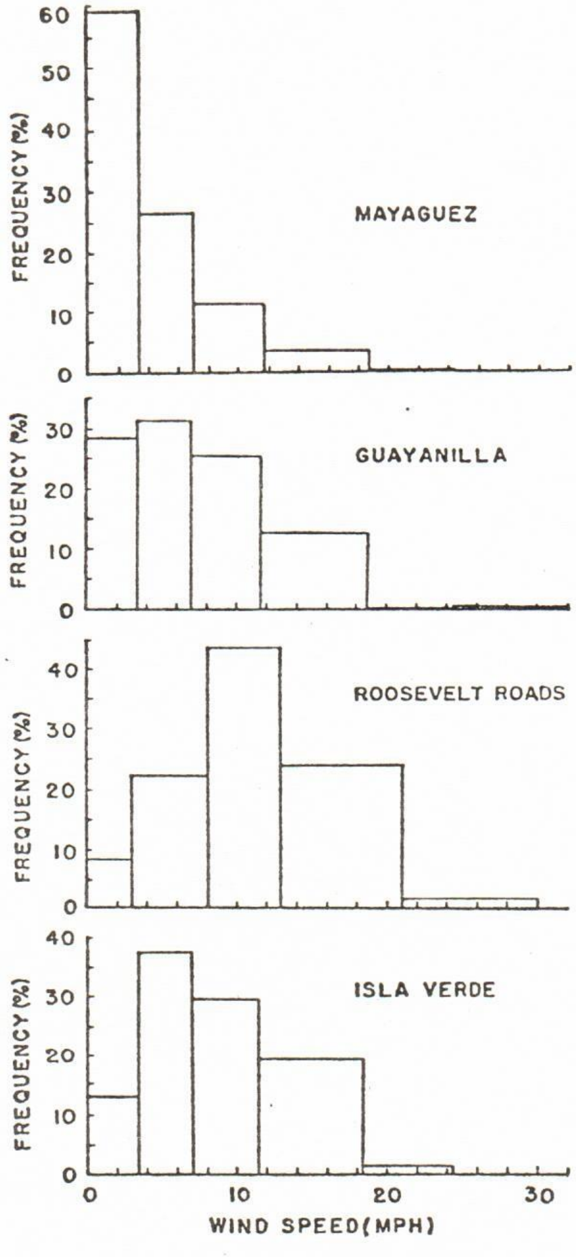

Fig. 5. Frequency distribution of hourly wind speeds for representative stations of the west, south, north and east coasts of Puerto Rico.

3. Distribution of wind power potential in Puerto Rico

In order to construct a map of wind power potential for the island, wind data was analyzed for the stations indicated in Fig. 4. A detailed frequency distribution of hourly wind speeds was readily available only for Guayanilla I. Distributions with only 5 or 6 wind speed classes were used for all other stations. In the latter case, detailed frequency distributions were reconstructed using the following method:

a. obtain a cumulative frequency distribution

b. fit a 2nd order polynomial to this cumulative distribution

c. Compute detailed frequency distributions from the adjusted curve.

Equation 1 was then applied to each of the wind speed classes (interval 1 mph) and the average wind power density computed.

The results are presented in Table 2. The results again indicate that the east coast is the region with the highest wind power potential, followed by the north coast. The south and west show only one third the power available in the East. It is interesting to note that the two stations in the North, separated by about 75 miles have very similar power potential. Contrary-wise, the stations in the South, although all fairly low, differ considerably among themselves. Guayanilla I is farther inland than Guayanilla II which is more exposed to the sea breeze effects. These local differences stress the need for a detailed wind survey before choosing the final site for a generator plant. The effects of valleys, ridges, exposure, location within the seabreeze circulation, etc., should be carefully considered.

The stations available are all within the populated coastal plains. It is important to asses the potential in the mountainous interior as well. To obtain an estimate for the elevated regions the following method was employed:

Table 2. Average wind power density in a vertical plane perpendicular to the wind direction (watts/m^2) during the year at selected stations in Puerto Rico. Values correspond to an anemometer height of 10 meters.

North Coast	
Ramey	52
Isla Verde	57
East Coast	
Roosevelt Roads	79
South Coast	
Santa Isabel	21
Guayanilla I (Fomento)	16
Guayanilla II (PPG)	39
West Coast	
Mayagüez	26

1. Obtain the frequency distribution of free-air wind speed at heights corresponding to the elevation of the terrain.

2. Apply Equation 1 after obtaining the air density appropriate to the elevation of the terrain.

3. Correct the resulting power for surface friction effects.

The U.S. Weather Service takes periodic upper air observations at the Isla Verde Airport station. Unfortunately, the data is not readily available in a summarized way by wind speed for different elevations. Colón (7) however, has presented some summarized data for a height of 5,000. From this information, a preliminary frequency distribution was reconstructed for free-air wind speed at 5,000 feet.

This height falls within the surface frictional layer which can extend up to 6,000 ft in the region. Thus, the winds at 5,000 feet should be related to the surface winds. A power law of the form:

$$U(Z)=U(a)(Z/A)^{1/7} \qquad (2)$$

(where u is the wind speed, Z is the height of interest, and a is a reference height) has been used (8) to relate winds at different heights near the surface. When this equation was applied to the average Isla Verde wind speed at 5,000 feet (17.1 mph) and 33 feet (8.4 mph) an excellent fit was achieved. In view of this good fit and lack of a better relationship, it was assumed in this study that the free-air wind speeds over Isla Verde are related by Equation 2 for the layer of up to 5,000 feet. Thus, the frequency distribution obtained for 5,000 feet was assumed to be valid for the entire layer after correction is made for the decrease in wind speed according to Equation 2.

The wind power was computed from Equation 1 for heights of 500, 1,000, 2,000 and 3,000 feet. The corresponding air density was obtained from the mean West Indies sounding of Jordan (9). A factor of 1/3 was applied to the computed power to allow for frictional drag effects as the air hits the elevated terrain. The adjusted powers constitute an estimate of the average wind power available at 33 feet over the ground at different elevations.

Fig. 6 is a map of Puerto Rico showing lines of equal wind power density (watts/m^2). The lines follow the 0.5, 1, 2 and 3 thousand feet height contours. The values represented by the lines correspond to the power density computed for those heights as described above. The point values obtained for the coastal stations are indicated separatedly on the map. The effects of river valleys and canyons and local terrain accidents have not been included in this general map. Local values of 85 watts/m^2 are probably possible in the tallest (3,500-4,000 feet) peaks.

It can be seen from this map that the highest wind power potential is found in the east coast and along the island mountain divide. The determination of the optimum location for a wind energy conversion system would have to be made after a detailed wind survey at the two more promising areas (east coast and divide). One of the most important factors to consider is the variation of the wind speed with height up to the hub height of the proposed turbine. The basic problem is to asses if the accelerating effect of the sea breeze in the coastal plane of the east coast provides a higher wind power at hub height than the stronger speed of the free-air wind as it passes over the tops of the tallest mountains at hub heights. From this preliminary assesment it looks like that an east coastal site would be as advantageous from the point of view of available power, accessibility, construction and operation. In the economic study which follows the Roosevelt Roads station will be used in the computations assuming that the wind energy generators would be placed there.

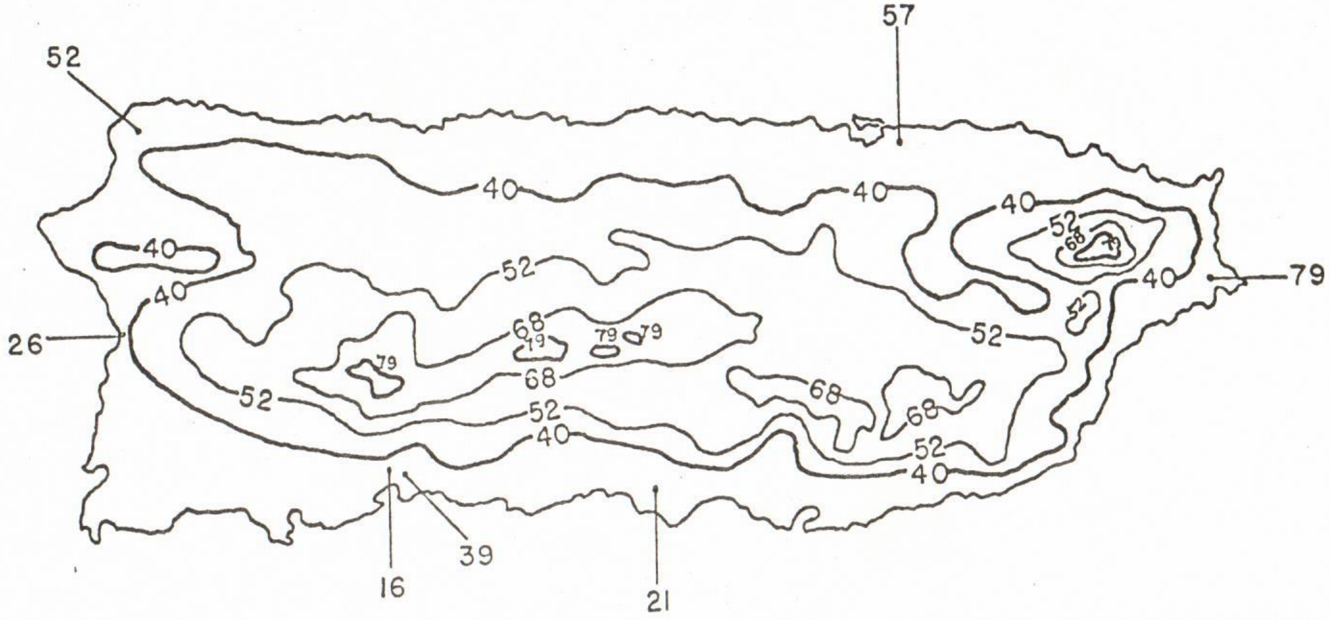

Fig. 6. Map of Puerto Rico showing lines of equal average wind-power density. These lines follow the approximate height contours of the terrain. Values of specific stations along the coast are plotted separately.

III Wind turbine performance

Two models of wind turbines are being designed and tested by the General Electric Company (10): a 500 kW unit, assumed to operate at a 12 mph median wind site, and a 1500 kW unit, assumed to operate at an 18 mph median wind site. The proposed design characteristics of these two units were used to estimate the energy that could be generated at a site like Roosevelt Roads.

The wind speeds of the frequency distribution for Roosevelt Roads were adjusted to the height of the hub of the two turbines by using the power law of equation 2. Then,the characteristic power-vs-wind-speed curve of each turbine was applied to the adjusted wind-speed distribution. The 1,500 kW unit would produce an average yearly power of 288 kW or 2.52×10^6 kWh during the year. The 500 kW turbine would generate an average of 236 kW or 2.07×10^6 kWh during the year. These two figures were used in an analysis of the cost of the power generated by arrays of these turbines and presented in the next section.

IV Economic analysis

1. System configuration

The hydroelectric system of the PRWRA produces approximately 100×10^6 kWh every year. To achieve a similar generation it would take approximately 50 wind turbines. Preliminary studies by GE have indicated that the wind turbine units should be installed with a separation equivalent to 15 diameters, of approximately 920 m between units. For a cluster of 50 units that would come to a minimum of 9 square miles of land needed for turbine installation alone. The entire Roosevelt Roads Naval Base for comparison, covers an area of 12.5 square miles. A more manageable cluster of 25 turbines would be more commensurate to the land limitations of the island. It is also possible to have lines of turbines strung along the east and north coasts. For the purposes of this study, a cluster of 25 turbines was considered. An effective layout could be as portrayed in Fig. 7.

2. Land costs

The land needed for the assumed layout is 2,891 acres (2,978 cuerdas). Current land prices in Puerto Rico fluctuate between $5,000 and $25,000 per cuerda (1 cuerda equals .9712 acres). Due to the large amount involved it is reasonable to assume a low wholesale price of $5,000 per cuerda. An 8% yearly increase is assumed in land prices. The present land costs would thus amount to $14.89 millions.

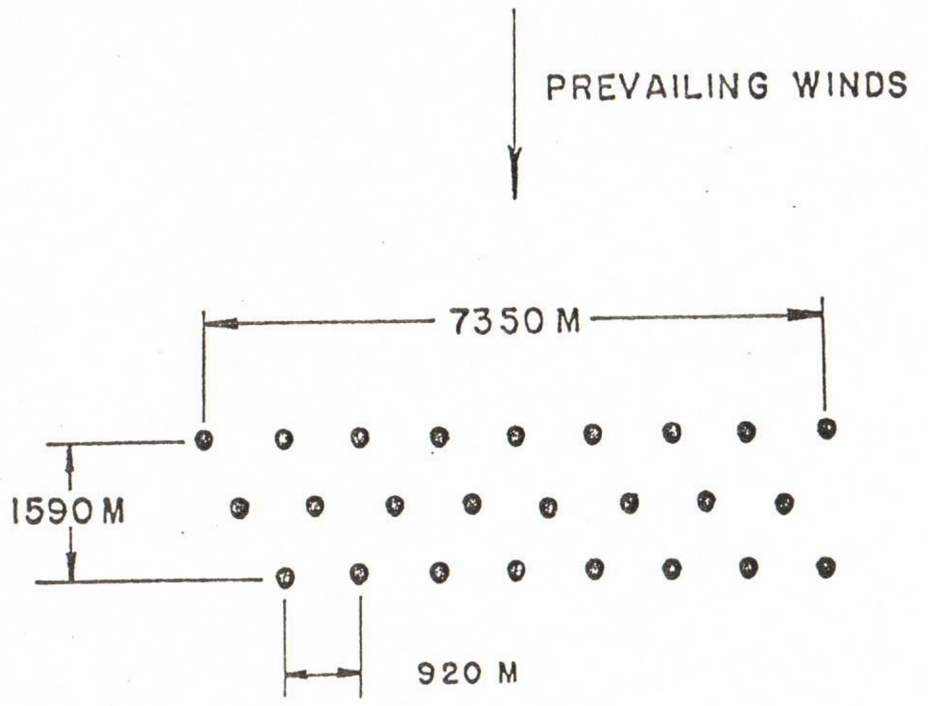

Fig. 7. Suggested layout for a cluster of 25 wind generators.

3. Wind turbine generators costs

Preliminary cost estimates provided by GE have indicated that the first production 1.5 kW would cost approximately $2.633 million. The 500 kW unit is estimated to cost 72.5% of this price, or $1.91 million. For initial planning purposes, GE also estimates that the accumulative average production costs can be reduced to 90% of the previous costs, each time the total number of units is doubled.

The manufacture of one turbine has been estimated by GE to take 6 to 9 months. The Bureau of Reclamation (5) is considering plans to purchase 49 turbines in the first 5 years of production. Other companies might enter into the wind turbine manufacturing business. A production of 100 units every 5 years will be assumed in the present study. Assuming a 90 percent learning curve, the average cost of a 1,500 kW system within the first 100 units (first 5 years of production) would be $1.31 million, and $0.95 million for a 500 kW unit. The total cost of the 25 turbines would be $32.75 and $23.75 million for the 1.5 and .5 kW models respectively. These costs include equipment, assembly, delivery, erection, land preparation and check out costs.

Every year the purchase is delayed the price will come down on the account of increased experience in the part of the manufacturer, but on the other hand, the price will go up on account of inflation.

4. Electrical connection costs and overhead

The Bureau of Reclamation has prepared a preliminary design as the basis for an estimate of the electrical interconnection costs for their wind turbine array of 49 units as well as the transmission facilities required to tie into their existing transmission grid. Their array would be twice as big as the one assumed for this study. Their costs have been estimated to be $6.37 million for their Wyoming site. Half of that amount could be assumed for the array of 25 units in Puerto Rico, or $3.19 million.

A design overhead of 17% has been added to cover engineering design and preliminary and environmental studies. An allowance for additional site facilities, contingencies and construction supervision of 15% has also been included.

The total capital investment for the system at this time are summarized in Table 3. The total cost for the wind turbine system comes to $62.33 and $50.45 million,if developed at the present time,for the 1.5 and .5 MW models respectively.

Table 3. Capital Investment Summary

Item	Capital Cost (million dollars) 1.5 MW	0.5 MW
1. Wind turbine generators (25 units)	32.75	23.75
2. Electrical interconnection	3.19	3.19
3. Design and study overhead (17%)	6.11	4.58
4. Contingencies, site facilities, supervision (15%)	5.39	4.04
5. Total wind power system	47.44	35.56
6. Land costs	14.89	14.89
Total capital investment	62.33	50.45

5. Wind turbine power costs

The power costs can be calculated using the capital investment costs, land costs, operation and maintenance costs, and the annual estimated power output. A construction period of 3 years is assumed, as well as a plant life of 35 years and an interest rate of 8%.

It was assumed that construction expenditures would occur uniformly throughout the 3-year construction period and the interest during construction was computed at compound interest for half of the construction years ($1.08^{1.5}$). The interest on the land cost was computed at compound interest for the 3 years of construction. Amortization of the total wind turbine investment (construction plus construction interest) was computed using a total capital fixed charge rate of 11.743% as is customary for the PRWRA while amortization of the land investment costs (land plus land interest) was assumed at 8% compound interest over the assumed 35-year life of the plant. GE has assumed that the maintenance and operation costs will be approximately 2 percent of the wind turbine costs. These costs were assumed to include the generators, electrical interconnections, and contingencies and site facilities.

Table 4 summarizes the estimated power costs. The total cost comes to $8.68 and $6.92 million for output of 63.00 and 51.75 million of kWh respectively, the power costs for the two wind turbine systems come out to be 137.8 and 137.7 mills/kWh.

Table 4. Power Costs

	Item	Costs (million dollars) 1.5 MW	 0.5 MW
1.	Total construction costs	47.44	35.56
2.	Construction interest on construction costs	5.81	4.35
3.	Land costs	14.89	14.89
4.	Construction interest on land costs	3.87	3.87
5.	Annual fixed charge on construction costs (1+2)	6.25	4.69
6.	Capital recovery on land costs (3+4)	1.61	1.61
7.	Operation and maintenance cost per year	.82	.62
8.	Total annual cost (5,6,7)	8.68	6.92
9.	Annual power output (10^6 kWh)	63.00	51.75
10	Power cost (mills/kWh)	137.8	137.7

The Bureau of Reclamation estimated a power cost of 21.1 mills/kWh for a similar system in Wyoming. The great difference in the two figures results from 3 very importan factors:

a. the wind power available in the Wyoming site is 3 times as much as in the Roosevelt Roads site.

b. the capital fixed charge rate for Wyoming was assumed at 8.41 percent, while the PRWRA reported a rate of 11.743 percent.

c. land costs in Wyoming were figured at $200 per acre while a wholesale price of $5,000 per acre was assumed for Puerto Rico.

It is interesting to note that both turbine models would produce energy at the same cost but the larger turbine would produce 18% more total power. Thus, it would be advantageous to use the larger machines. In what follows only the 1.5 kW turbine model will be considered.

V Economic projections

The estimate of 138 mills/kWh applies to the cost of power if construction was completed within the next 5 years. For simplicity, no inflation factor was included for this period. Certainly, the uncertainty in the learning rate estimates and the manufacturing output do not warrant a more detailed approach. As construction is delayed beyond this period, however, the price will change considerably: down on account of increased experience in the part of the manufacturer, but up on account of inflation.

A projection of the wind power costs was made for a period of 40 years. This projection was made in eight 5-year steps assuming the production of 100 additional turbines in each 5 year period with a corresponding 90% learning rate. A compound 8% inflation rate was also assumed starting from the costs of the estimate of Table 4. It was further assumed that the learning rate takes into consideration the inflation in the production process.

Table 5 presents the capital investment costs for each of the eight 5-year periods. The greatest drop in the price of the generators occurs in second step. The learning curve is basically an exponential curve which drops very fast at the beginning and stabilizes very fast. Other costs, especially for land, escalate very fast on account of the assumed 8% inflation. Actually, land and interconnection costs become several times the cost of the turbines themselves. If an additonal inflation increase is added to the cost of the turbines the situation becomes hopeless very fast. The largest item becomes the land costs after 10 years of delay. If the land could be secured free of charge, e.g., land belonging to the Commonwealth of Puerto Rico, or land already belonging to the PRWRA could be used, the costs could be reduced dramatically.

Table 5. Forty year projection of capital investment (million dollars)

	Years							
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1. 25 generators	32.75	26.15	24.15	22.90	22.08	21.4	20.85	20.40
2 Electrical interconnections	3.19	4.69	6.89	10.11	14.86	21.85	32.10	47.16
3. Design overhead (17%)	6.11	5.24	5.28	5.61	6.28	7.35	9.00	11.49
4. Contingencies (15%)	5.39	4.63	4.66	4.95	5.54	6.49	7.94	10.13
	47.44	40.71	40.98	43.57	48.76	57.09	69.89	89.18
5. Land costs	14.89	21.88	32.15	47.23	69.40	101.97	149.83	220.15
	62.33	62.59	73.13	90.80	118.16	159.06	219.72	309.33

Table 6 shows a summary of the power cost estimates for each of the 5-year periods. Again, the effect of inflation overcomes the advantage from the learning rate. Line 9 of the table shows the savings of oil barrels that the wind system could achieve assuming that the efficient thermoelectric plant uses one barrel to generate 600 kWh. Line 11 indicates the equivalent cost of each barrel saved in dollars.

Figs 8 and 9 portray graphically the investment cost of each kW produced and the equivalent cost of each barrel of oil that could be saved by the wind energy conversion system. For reference, the portion that the land and the turbine purchase would account for is also portrayed in Fig. 8. It should be realized that in the computations figured above, no provision has been made for outages or auxiliary power for the turbine. In view of the inaccuracies in some of the assumptions this correction becomes insignificant. If a more detailed estimate is desired, however, the total annual power output could be reduced by a factor of .90X.99 which is a reasonable figure for outage and auxiliary power, respectively.

Line 12 of Table 6 shows the equivalent cost of each barrel of oil saved if the land cost could be eliminated. The equivalent cost could be around 60-70 dollars per barrel for the next 25 years. In view of the present upward trend in oil cost, the equivalent price could become competitive in the foreseable future. Land cost could be eliminated by using land already owned by PRWRA or ceded to PRWRA free of charge. Fig. 9 portrays graphically the equivalent cost of a barrel of oil under these assumptions.

Table 6. Forty year projection of power costs (million dollars)

			YEARS					
	0-5	6-10	11-15	16-20	21-25	26-30	31-35	36-40
1. Total construction costs	47.44	40.71	40.98	43.57	48.76	57.09	69.89	89.18
2. Construction interest on construction costs	5.81	4.98	5.01	5.33	5.97	6.99	8.55	10.91
3. Land costs	14.89	21.88	32.15	47.23	69.40	101.97	149.83	220.15
4. Construction interest on land costs	3.87	5.68	8.35	12.27	18.02	26.48	38.91	57.18
5. Annual fixed charge (1+2) on construction costs	6.25	5.37	5.39	5.74	6.43	7.52	9.21	11.75
6. Capital recovery on land costs (3+4)	1.61	2.36	3.47	5.11	7.50	11.02	16.19	23.79
7. Operation and maintenance costs per year	.83	.71	.71	.76	.85	.99	1.21	1.55
8. Total Annual cost (5+6+7)	8.68	8.44	9.57	11.61	14.78	19.53	26.61	37.09
9. Annual power output (10^6 kWh)	63.00 (105,000 barrels of oil)							
10. Power cost (mills/kWh)	137.8	134.0	151.9	184.3	234.6	310.0	422.4	588.7
11. Equivalent oil costs ($/BBL)	75	80	91	111	141	186	253	353
12. Equivalent oil costs not including land costs ($/BBL)	67	58	58	62	69	81	99	127

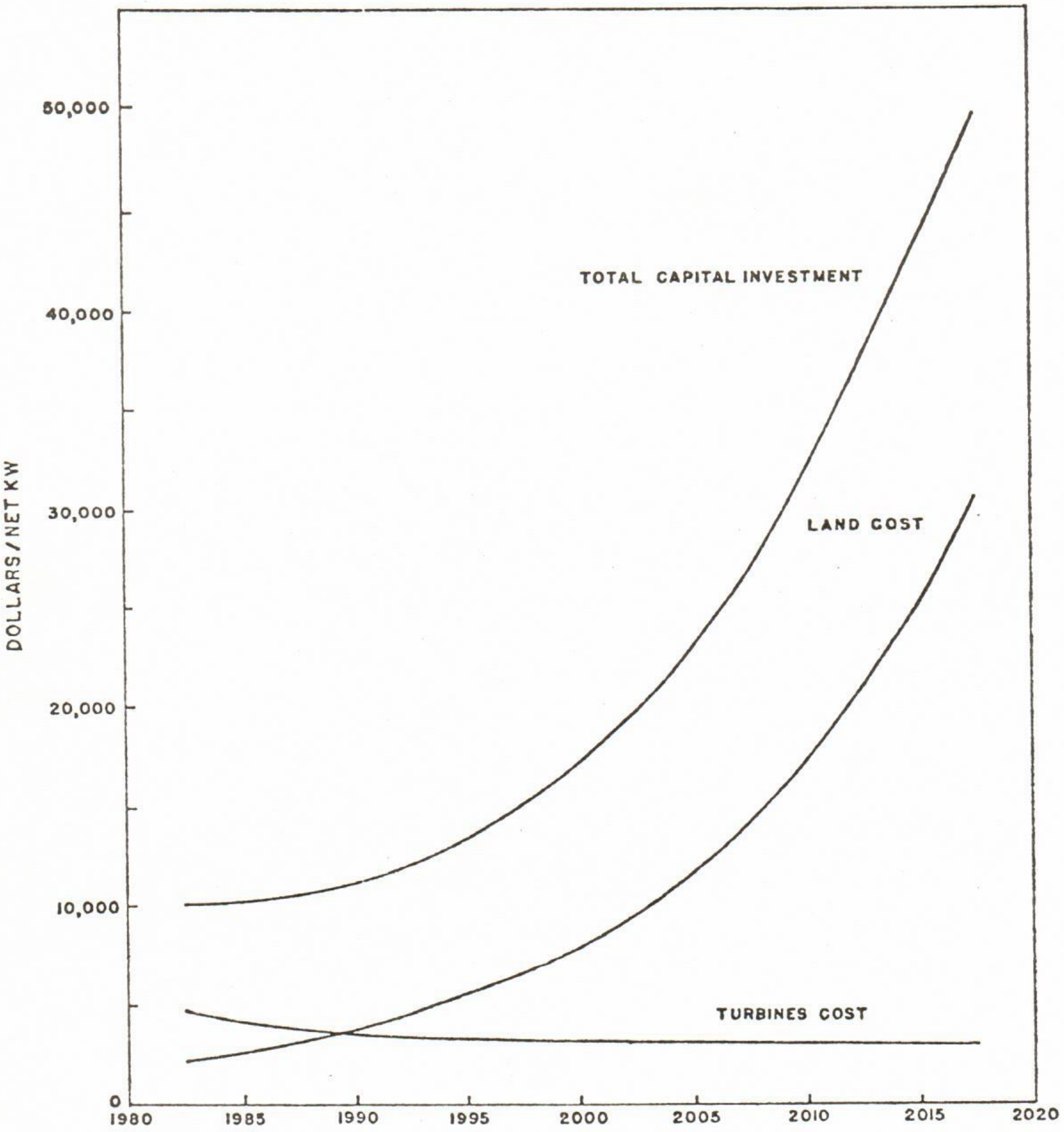

Fig. 8. Forty-year projection of the equivalent cost of each kW produced by the wind-energy conversion system.

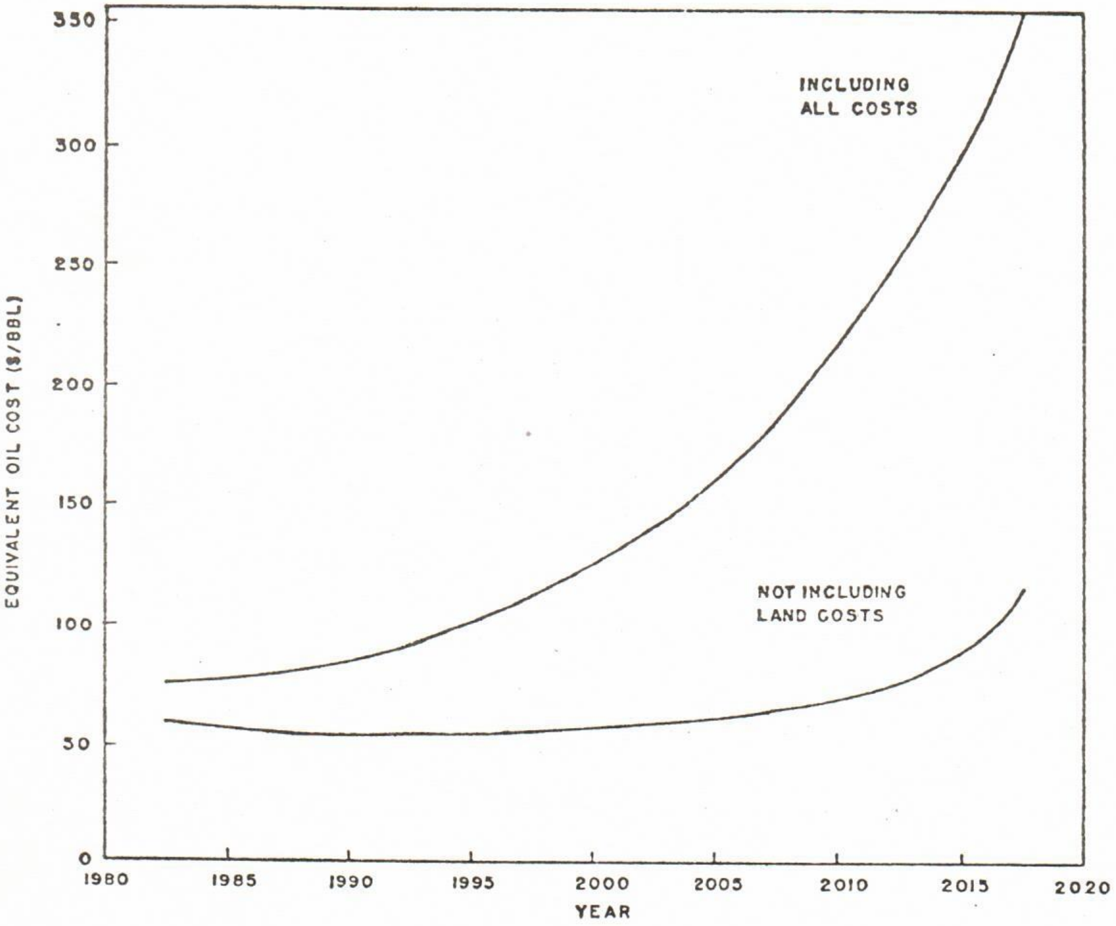

Fig. 9. Forty-year projection of the equivalent cost of each barrel of oil saved by the wind-energy conversion system.

VI Summary

A study has been made of the possibility of integrating large windpower generators to the existing PRWRA thermoelectric network in Puerto Rico. Climatologically, one would expect the highest potential for wind power utilization in the north and east coasts because the sea breeze acts to intensify the prevailing winds in those regions. Actually, an inspection of the available stations around the island reveals that the largest power densities are found in the north and east coasts. The power at the south and west coasts being very low. Estimates of wind power density for other regions, especially the mountainous interior, indicate that no appreciable advantage is found in the mountains over the eastern coastal plains.

A station in the east coast, Roosevelt Roads, was subsequently chosen for detailed analysis. Applying the design characteristics of the GE 1.5 and .5 MW to the wind speed distribution for this station reveals that an average power of 288 kW and 236 kW respectively, could be generated throughout the year.

A system of 25 turbines is proposed. Estimates of capital investment, operation and maintenance were made for systems of the two models. The total power costs were estimated at 137.8 and 137.7 mill/kWh. Three major factors account for such an elevated production cost:

(1) the wind power potential is moderate
(2) the capital fixed charge is very high
(3) land costs are extremely high.

A 40 year economic projection was performed. In general, reductions due to the assumed learning curve were more than compensated by the inflation rate of 8%. The largest item being the escalation of the already high land cost. If land costs could, somehow, be eliminated, the equivalent cost of each barrel of oil saved could be around 60-70 dollars for the next 25 years. A price that could become competitive in the foreseable future. Land costs could be eliminated by using land already owned by PRWRA or ceded to PRWRA free of charge.

Bibliography

1. "Future Electric Power Production in Sweden", L. Norlin, February 1976.

2. "Swedish Wind Energy Program, A Three Year R&D Plan-1975-1977", Presented at the Second Workshop on Wind Energy Conversion Systems, O. Ljungstrom, June 1975.

3. "Swedish Wind Energy R&D Program 1975-1977, Goals Specification for System Analysis Models and Final Reporting 1977", Edited by O. Ljungstrom, November 1975.

4. "Wind Energy Resources Model for Sweden-Preliminary Survey, Phase I", L. Olsson, et al., December 1975.

5. "A Proposed Conceptual Plan for Integration of Wind Turbine Generators with a Hydroelectric System" S. J. Hightower and A.W. Watts, Bureau of Raclamation, U.S. Department of the Interior, March 1977.

6. "Tropical Meteorology", H. Riehl, Mc Graw-Hill Book Co. Inc., New York.

7. "Climatología de Puerto Rico", J. A. Colón, U.S. Weather Bureau.

8. "Wind Power Climatology", J.W. Reed, Weatherwise, 27, 237-242, 1974.

9. " A Mean Atmosphere for the West Indies Area", Report No. 6, National Hurricane Research Project, Florida, May 1957.

10. "Final Report, Design Study of Wind Turbines (50kW-3,000kW) for Electric Utility Applications, Analysis and Design", NASA Lewis Contract NAS3-19403, GE-SD-No. 76SDS 4209, General Electric, February 1976.