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SITE SELECTION TECHNIQUES AND METHODOLOGIES FOR WECS

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SITE SELECTION TECHNIQUES AND METHODOLOGIES FOR WECS

Introduction

The question of siting a wind energy conversion system, or systems (WECS), represents a balance between economic and technical criteria and the environmental and social values of the user and the local citizens, whether the WECS is for a small farm or a utility serving a multi-state region. The social and environmental issues that play a role in siting are the visual impacts of the WECS, zoning or code restrictions, liability considerations, the "wind rights" question, noise, aviation hazards, effects on birds, effects on communication systems, and other family and neighborhood values. Some of the important economic values are the cost of the site analysis, the value placed on the increased power production that results from investing more in system components (such as a higher tower or a larger blade), site related construction costs, access roads and transmission line costs, and the life-cycle cost of maintaining and operating a WECS installation. Finally, the technical siting issues include the meteorological characteristics of the candidate site that contribute to the efficient and safe production of power by wind, the potential weather hazards of the site in question, and the terrain and seismic features of the site. These technical issues are highly related to the size and type of the proposed WECS and the type of storage system (if there is one) required for the installation. In conclusion, a good siting policy is one that optimizes the power output based on the constraints imposed by these various issues.

Issues Considered Here

This paper deals with the technical aspects of siting. If we can improve the siting of WECS from the meteorological and the topographical points of view, then the overall siting policy can be improved. The economic benefits of these improvements will be, at least, fourfold:

A saving in siting costs for WECS.

More energy produced per unit due to locating units in more ideal wind regimes.

3. A more predictable, dependable, and constant source of power due to improved siting criteria.

4. A safer installation due to the avoidance of meteorological and topographical hazards.

The Ideal Data Set

The potential user and the manufacturer of WECS would like to have an extensive data set describing the meteorological, hydrological and geological properties of the area in which turbines may be sited. Some of the items in this data set are as follows:

1. The distribution of the hourly mean wind speeds.

2. The distribution of the hourly mean wind directions.

3. The turbulent and gust characteristics of the sites.

4. The persistence of the wind speed and direction at the candidate sites, and the prevailing winds throughout the year.

5. The terrain features and the surface roughness in the neighborhood

of the candidate sites.

6. The terrain features and surface roughness upstream of the potential sites in the directions of the prevailing winds.

7. The presence of flow separation zones and the sites of accelerated flow in the area.

8. The veering of the wind and the vertical wind shear as functions of atmospheric stability and surface conditions.

9. The frequency and magnitudes of extreme winds in the area.

- 10. The frequency and length of the time periods of near calm winds.
- 11. The frequency of severe thunderstorms (such as, storms with severe gusts, lightning, hail, and possibly tornadoes).

12. The frequency of hurricanes.

13. The mean air density, annual solar radiation and hours of sunshine, and the annual and seasonal mean temperatures.

14. The temperature extremes.

15. The mean precipitation, the mean and extreme snowfalls, and the frequency of frozen precipitation and icing.

16. The frequency of occurrence of extreme precipitation.

17. The occurrence of salt spray and blowing dust.

18. The possibility of flooding.

19. The bearing capacity of the soil.

20. The potential for earthquakes.

Why Are We Data Poor?

If the data listed in the previous section were available from long term records (at least five years for meteorological data), then the user, along with the manufacturer or distributor of the WECS, and possibly a consultant, could adequately survey the available land for potential wind sites and choose the best available sites for the WECS. However, we rarely have this much data of high quality to work with in siting WECS. In fact, our data base is usually quite poor.

The reason for this data poor condition for the site selection of WECS can be explained through the use of Figure 1. In this figure we have indicated the important time and space scales in three areas of investigation of wind power systems. The areas of interest are presiting evaluation or the national and regional wind power assessment, site selection, and the design and evaluation of WECS. The meteorological data that is used in the presiting evaluation basically comes from the National Weather Service (NWS). This data is interpolated over the various regions of the country and gives an adequate assessment of the wind power on horizontal scales down to about 100 km in non-complex terrain and down to a week or so on the time scale.

Much of the meteorological data required to design and evaluate WECS can be of a generic nature. For example, the gust data required in the design of a turbine can be generated at locations other than the specific site. If the designer has an idea of the gust characteristics of the site, a determination can be made concerning whether the gust intensities are low, medium or high. Once this is determined, the designer can use the generic data for the particular intensity category and go-on with the design. Obviously, some of the data required to design and evaluate WECS will be site specific; however, much of the required data in this area can be generically obtained.

The meteorological data required to conduct a successful site selection procedure cannot adequately be obtained from the <u>interpolation</u> of NWS data because the coverage by these data for areas less than 10,000 sq km is so poor, and poorer still in mountainous areas. Hence, the NWS data must be <u>extrapolated</u> to the sites of interest through the use of mathematical and physical models, as well as on-site meteorological measurements. The process of data extrapolation becomes more complex as the terrain becomes more complicated. An additional complexity of transferring NWS data to candidate wind energy sites is the fact that most of the short-term weather phenomena occur over the space and time scales important to the site selection process, Figure 1. That is, the site process is greatly influenced by the occurrence of severe storms, low level jets, and weather fronts; and these weather phenomena may affect the candidate sites differently than the National Weather Stations.

To help alleviate this problem, we have summarized the current state of knowledge of air flow over various land forms. Recommendations are given concerning the best siting locations on, or near, a given land form. In addition, we have discussed the current state-of-the-art techniques for transferring NWS data (or other long term data sets) to the candidate turbine sites.

Flow Over Land Forms

The behavior of near-surface winds over relatively flat ground, and the increase in their speed with height, are fairly well known, but comparatively little precise information exists on airflow over various land forms such as, cliffs, hills, mountains and valleys.

The relative merits of ridges, isolated hills, mountains, gaps, and valleys as potential wind power sites have been investigated in the past but the information is far less complete and precise than it is for airflow over relatively homogeneous terrain. In fact, some land forms as possible wind power sites have not been seriously investigated at all.

Generally, land forms or terrain may be classified as:

1. Homogeneous terrain.

2. Nonhomogeneous terrain (the internal boundary layer).

3. Cliffs.

- 4. Terraces and Benches.
- 5. Mesas and Buttes.
- 6. Hills and Ridges.
- 7. Mountains.
- 8. Passes and Saddles.
- 9. Valleys and Canyons.
- 10. Gaps (Gorges).
- 11. Slopes.
- 12. Basins.
- 13. Aeolian land forms.
- 14. Complex terrain.
- 15. Islands.
- 16. Shelterbelts and buildings.

The last item in this list is obviously not a geological land form, but it was included for the sake of completeness.

• Land forms exist on different horizontal and vertical scales and consequently their effects on atmospheric motions and associated weather also exist on different horizontal and vertical scales, and for different time scales. Figure 2 is one attempt to classify terrain effects, or modification of atmospheric motions, according to an atmospheric scale division of Orlanski [1].* This illustration shows that terrain effects occur over a wide spectrum of length and time scales. The list is by no means complete and is used merely for illustrative purposes, nor is it meant to imply that terrain effects with similar time or horizontal space scales have dynamic similarity.

As indicated in Figure 2 various land forms can influence atmospheric motions at all scales, from the scale of the long-wave ridge and trough down through those of lee and wake phenomena to small turbulent eddies. Terrain features effect atmospheric motion in three ways: 1) through boundary layer effects as the result of surface friction (roughness) and local pressure gradients; 2) by the barrier or orographic-dynamic effect caused by blocking of airflow, spatial pressure differences and perturbations of airflow; and 3) through thermal effects (heating and cooling) due to vertical and spatial temperature gradients. In a general way, these effects are represented schematically in Figure 3. At an actual site in complex terrain all three of these effects (roughness, thermal, dynamic) will operate together. The importance of a given effect will change from day to night, day to day, from season to season and will also depend on the larger-scale airflow patterns.

Since it is desirable to be able to analyze potential wind energy sites quickly, it is unfortunate that quantitative information for all these important effects are not precisely known for complex terrain features. Some quantitative information is available from past and present studies for some land forms such as, hills or ridges but is lacking for other terrain types. A number of field, numerical, and laboratory investigations of

^{*}The square brackets refer to the references at the end of this paper.

airflow over topography, not specifically oriented toward wind power site selection, are available for review and this information can provide some insight into the siting problem.

There are already some general factors that can be recognized as "good" siting criteria for various land forms irrespective of the type of terrain. The important point is that some land forms may satisfy these siting criteria better than others and therefore it is necessary to find additional criteria based on the characteristics of the land forms and their effect on airflow that will give the optimum criteria. Some of the "good" siting criteria are the following:

1. Persistent mean wind speeds >4 ms⁻¹ and few calm periods.

2. Relatively persistent mean wind directions.

3. Small diurnal and seasonal variations in wind speeds and direction.

4. Small vertical wind shear in the lower 300 m.

5. Low turbulent intensity.

6. Low frequency of environmental hazards to wind turbines

Techniques for Extrapolating Data

dependent on the site at which the turbine is located. While the variations from site to site within a few kilometers of each other in relatively flat and homogeneous terrain are far from negligible, in regions of inhomogeneous and complex terrain these variations can be large enough to strongly affect the economic feasibility of wind energy. As we have seen, an added complexity is the sparceness of data in those areas most important to the siting of wind turbines.

Figure 4 depicts the site selection problem that faces us. For regions of inhomogeneous and complex terrain, with horizontal scales on the order of a few hundred kilometers, there is very little representative meteorological data available. The data from the National Weather Service (NWS) Stations 1 to 4 may be sufficient to define some of the hazards and weather extremes that occur over the Potential High Wind Areas A, B, C; but the data cannot, in general, be accurately interpolated to give good wind records at sites within Areas A, B, C. Hence, some sort of extrapolation, or onsite technique of analysis, will have to be applied to properly assess the wind characteristics at candidate sites in Areas A, B, C.

The techniques in use or currently being developed for solving this problem, without taking long term (at least five years) meteorological measurements onsite, are as follows:

1. Rules of Thumb.

2. Statistical Methods with Short-Term Onsite Meteorological Measurements.

3. Biological and Geological Indicators.

4. Physical Models and Fast, Efficient Numerical Models.

5. Large Numerical Models - Siting Methodologies.

Obviously, the ideal situation is to have long term measurements onsite; but, this is rarely the case. Table I lists in the order of preference the techniques that should be used for site screening and site localization in situations similar to the one depicted in Figure 4. The order of listing the techniques in Table I is not related to the economics of using the technique but merely to the technical success and accuracy of the methods. The cost analysis of the various methods has not been completed; in fact, many of the techniques have not been fully developed.

Figure 5 indicates the time and space scales over which the various extrapolation techniques are capable of supplying information that will be useful in siting wind turbines. In some cases the boundaries for a given method may either be larger or smaller than those shown in Figure 5; however, we feel that the time-space boundaries shown on the figure are representative. The "siting handbooks" referred to in Figure **5** are handbooks showing flows over generic type land forms and these handbooks will only be useful for onsite investigations. The "various combinations" is a time-space region where information may be gained from applying a variety of the techniques, such as, numerical modeling, siting handbooks, and physical modeling. Finally, the large scale models being used in comprehensive "siting methodologies" are of two general types: steady-state models and time-dependent systems. The timedependent system cannot be run continuously in a cost effective manner. for more than a few days of simulated time. Hence, for seasonal and annual analyses, steady-state models applied to a small set of characteristic large scale flow patterns is the only cost-effective type of numerical modeling. In the "combination numerical modeling" region in Figure 5. the thought is that the time-dependent model with a one kilometer or so grid will supply information to drive the steady-state model on a finer grid.

References

1. Orlanski, I., "A Rational Subdivision of Scales for Atmospheric Processes," Bull. Am. Meteor. Soc., 56(5), 527-530, 1975.

FIGURES

Captions

- Figure 1. The Time and Space Scales of Importance In the Site Selection Process
- Figure 2. A Classification of the Effects of Terrain on Atmospheric Motions, After Orlanski [1].
- Figure 3. Methods In Which Terrain Features Affect Atmospheric Motions.

 The quantity 0 is the potential temperature, PBL is the planetary boundary layer and MBL is the mountain boundary layer.
- Figure 4. A Schematic of the Site Selection Problem In Complex Terrain
 When There Is A Lack of Long-Term Data
- Figure 5. The Relationships Between the Extrapolation Tools and the Important Time and Space Scales for Site Selection

TABLE .

- Table I Techniques for Getting Onsite Data for Site Screening and Localization
 - A. Annual and Season-to-Season Variations in Wind Speed and Direction
 - 1. Onsite Measurements
 - 2. Numerical Modeling
 - 3. Physical Modeling
 - 4. Geological and Biological Indicators
 - B. Month-to-Month Variations in Wind Speed and Direction
 - 1. Onsite Measurements
 - 2. Numerical Modeling
 - Physical Modeling
 - C. Diurnal Variations in Wind Speed and Direction
 - 1. Onsite Measurements
 - 2. Numerical Modeling
 - D. Frequency of Low Power and Downtime
 - 1. Onsite Measurements
 - 2. Numerical Modeling
 - E. Turbulence and Other Hazards.
 - 1. Onsite Measurements
 - Generic Flow Patters, Including Those Generated by Physical Models
 - 3. Hazard Data from Handbooks
 - 4. Numerical Modeling

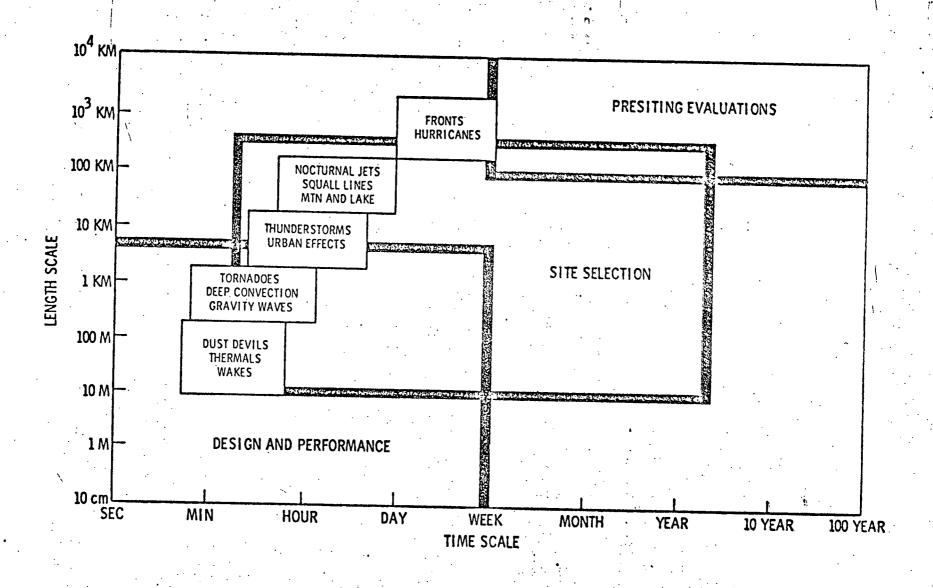


FIGURE 1. The Time And Space Scales of Importance In The Site Selection Process.

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-		108	MACROSCALE a	GLOBAL MOUNTAIN AREA	SUBTROPICAL, I GLOBAL WIND PA LONG-WAVE RIDO				
		10	MACROSCALE B	CONTINENTAL MOUNTAIN AREA	MONSOONS	STORM TRACKS CYCLONES AND ANTICYCLONES			
		10 ⁶	(SYNOPTIC) MESOSCALE Ø	REGIONAL MOUNTAIN AREA		AIR M FRONTS CYCLO			
	3000	•	MESOS CALE B	MOUNTAIN- VALLEY (PLAIN) BAS IN ISLAND		SL(VA CH	WINDS WAVES DPE-VALLEY WIND LLEY-PLAIN WIND ANNELING KE EFFECTS	•	
	-	10 ²	MESOS CALE Y	HILLS RIDGES GORGE CANYON		•	BLOCKING AIRFLOW SPEED-UP WAKE EFFECTS CHANNELING CANYON WIND		
	300	1	MICROSCALE a	CLIFFS MESAS TERRACES GAP			AIRFLOW SEPARATIONS AN WAKES CHANNELING	D	
	200	10 ⁻²	MICROSCALE B	CLIFFS LARGE ROUGHNESS ROUGHNESS TREES			VER WIN PRO	LOW SEPARATION FICAL D FILES BULENCE	
	30	10 ⁻⁴	MICROSCALE Y	TREES VEGETATION SMALL ROUGHNESS	: · ·		VER	TICAL WIND PROFILES TURB	JLENCE
-		-	ORLANSKI CLASSIFICATION	GENERAL LANDFORM OR ROUGHNESS	CLIMATOLOGIC SCALE	CAL SYNOPTIC PLANETARY		MICRO	SCALE

FIGURE 2. A Classification Of The Effects Of Terrain On Atmospheric Motions, After Orlanski [1].

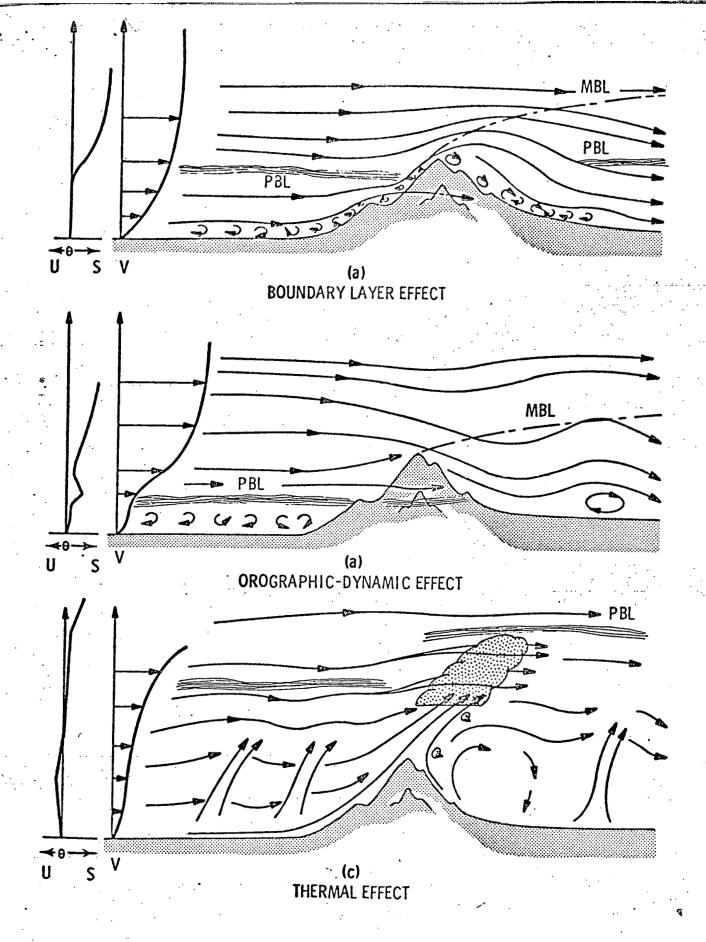


FIGURE 3. Methods In Which Terrain Features Affect Atmospheric Motions. The quantity θ is the potential temperature, PBL is the planetary boundary layer and MBL is the mountain boundary layer.

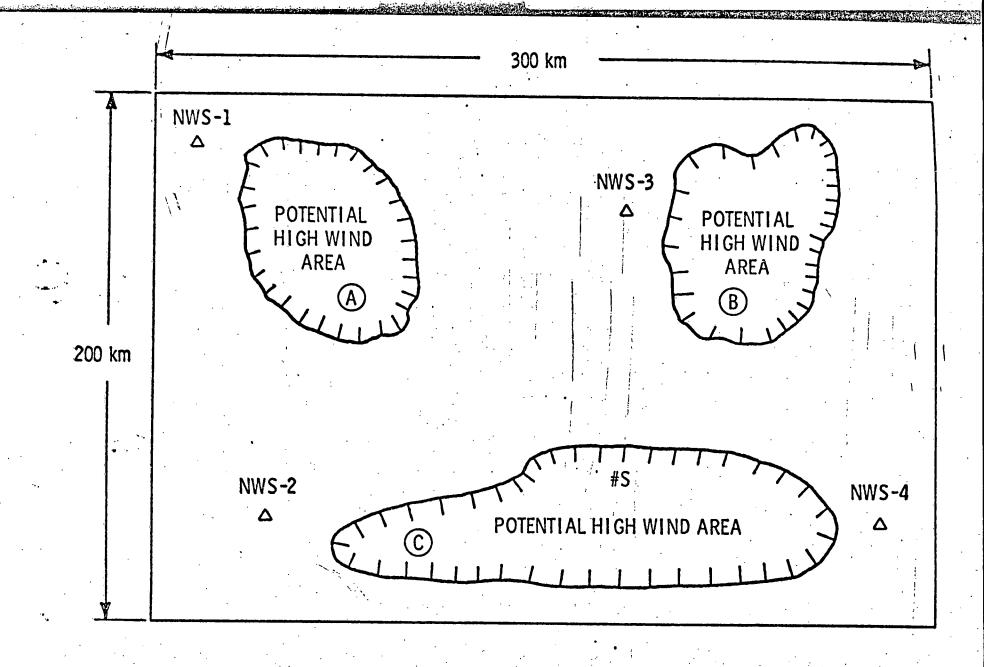


FIGURE 4. A Schematic Of The Site Selection Proglem in Complex Terrain When There Is A Lack Of Long-Term Data.

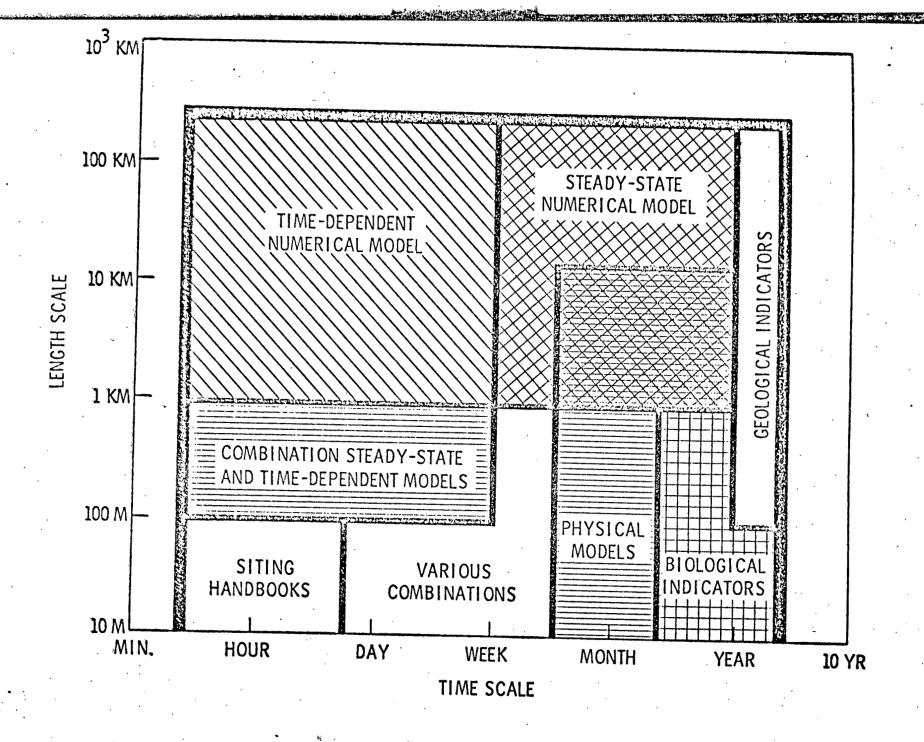


FIGURE 5. The Relationships Between The Extrapolation Tools And The Important Time And Space Scales For Site Selection.