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Wind Generation in the Future Competitive California Power Market

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Contents

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Acronyms and Abbreviations

CAD	Computer-aided design
CEC	California Energy Commission
CPUC	California Public Utilities Commission
DEM	Digital Elevation Map
DOI	U.S. Department of the Interior
EDF	Environmental Defense Fund
ESRI	Environmental Systems Research Institute
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
ITRE	Iterative Test of Resource Effectiveness
LBNL	Lawrence Berkeley National Laboratory (Berkeley Lab)
NREL	National Renewable Energy Laboratory
USGS	U.S. Geological Survey

Abstract

The goal of this work is to develop improved methods for assessing the viability of wind generation in competitive electricity markets. The viability of a limited number of possible wind sites is assessed using a geographic information system (GIS) to determine the cost of development, and Elfin, an electric utility production costing and capacity expansion model, to estimate the possible revenues and profits of wind farms at the sites. This approach improves on a simple profitability calculation by using a site-specific development cost calculation and by taking the effect of time varying market prices on revenues into account.

The first component of the work is to develop data characterizing wind resources suitable for use in production costing and capacity expansion models, such as Elfin, that are capable of simulating competitive electricity markets. An improved representation of California wind resources is built, using information collected by the California Energy Commission (CEC) in previous site evaluations, and by using a GIS approach to estimating development costs at 36 specific sites. These sites, which have been identified as favorable for wind development, are placed on Digital Elevation Maps (DEMs) and development costs are calculated based on distances to roads and transmission lines. GIS is also used to develop the potential capacity at each site by making use of the physical characteristics of the terrain, such as ridge lengths. In the second part of the effort, using a previously developed algorithm for simulating competitive entry to the California electricity market, the Elfin model is used to gauge the viability of wind farms at the 36 sites.

The results of this exercise are forecasts of profitable development levels at each site and the effects of these developments on the electricity system as a whole. Under best guess assumptions, including prohibition of new nuclear and coal capacity, moderate increase in gas prices and some decline in renewable capital costs, about 7.35 GW of the 10 GW potential capacity at the 36 specific sites is profitably developed and 62 TWh of electricity produced per annum by the year 2030. Most of the development happens during the earlier years of the forecast. Sensitivity of these results to future gas price scenarios is also presented. This study also demonstrates that an analysis based on a simple levelized profitability calculation approach does not sufficiently capture the implications of time varying prices in a competitive market.

1. Introduction

The goal of this work is to develop improved methods for assessing the viability of wind generation in competitive electricity markets. In this phase, the profitability of a limited number of sites is estimated, and the likelihood of development determined. The approach improves on current capacity expansion approaches in a number of ways.

1. Rather than depending on a single generic resource to represent wind potential, a number of actual sites are evaluated individually.

2. The cost of development at each site is estimated using both generic technology cost information and site specific information.

3. Wind farm revenues are estimated based on patterns of generation derived from actual wind observations and estimates of time-varying market prices. In addition to attempting to improve on standard practice for capacity expansion modeling, this paper also demonstrates the benefits of such an approach when compared to simple levelized cost analyses.

The first step in the process is characterizing wind resources in a manner suitable for inclusion in production costing and capacity expansion models of electric power systems, such as the Elfin model, that are capable of simulating competitive markets. This characterization is typically in the form of a data set for model input that embodies the three key features that determine the viability of wind development: (1) estimates of the total resource; (2) estimates of the costs of developing the resource, and (3) an estimate of hourly potential generation. The information in (3) is of the utmost importance because it allows estimation of a potential revenue stream from sales into a competitive electricity market. Specifically, in this demonstration, an improved representation of the California wind resource is developed in the form of an Elfin data base, using information collected in previous site evaluations conducted by the California Energy Commission (CEC) and by using a geographic information system (GIS) approach to estimating development costs at specific sites. The Elfin model then uses these data to gauge the viability of wind farms at 36 specific sites. The results of this exercise are forecasts of profitable levels of development at each site, and forecasts of the effects of these developments on the electricity system as a whole, on fuel consumption, emissions, pool prices, etc.

2. Methods

Elfin

The Elfin[1] model is a production costing and capacity expansion simulation program that has been widely used in California and elsewhere. Elfin uses a load duration curve dispatch simulation method, and picks an expansion program for the industry using the Iterative Test of Resource Effectiveness (ITRE) algorithm (EDF 1997). ITRE provides particularly attractive characteristics for work of this kind. ITRE is a simple search algorithm in which the most profitable new investments are made first and other investments chosen to the point that no further profitable new plant construction can be made. While this approach does not guarantee an optimal result and can lead to lengthy searches for the multiple possible equilibrium combinations of new investments, ITRE is capable of considering a large number of potential resource additions. In contrast to more common search methods, such as dynamic programming, choosing between many specific investment options does not lead to an insurmountable curse of dimensionality. Despite the vast number of combinations of investments possible at 36 wind sites over a 25-year period, ITRE successfully delivers results in reasonable computing times, typically a few days, on a Sun workstation.[2] The ability to assess the viability of numerous alternatives is particularly important when multiple renewable generation options are to be evaluated because these tend to have much more variable characteristics than thermal technologies. In other words, while from an engineering standpoint, a modular combustion turbine can operate similarly anywhere within the state, wind sites will exhibit quite different output patterns. The Berkeley Lab has previously set up an Elfin model of the future California Pool. This database is a simple aggregation of the existing thermal generating resources owned by the incumbent investor-owned utilities together with in-state non-utility generators. The Berkeley Lab and EDF have also developed and implemented an algorithm for estimating the profitable level of entry by new capacity into the California market and for finding the combination of new investment that is the most profitable for investors (Marnay et al. 1997a).

To date, modeling of the California electricity market by the Berkeley Lab has focused on broad magnitudes of entry by new capacity, including renewable generators. Wind has consistently emerged as one of the renewable resources closest to commercial viability, but, prior to this work, no effort has been made to identify the exact extent and characteristics of wind resources within or near to the state; rather, wind has been represented within the Elfin model in the form of a simple generic generating resource with unlimited supply at a stated fixed development cost. Since wind generation appears to be the renewable resource most

1 Elfin is a proprietary product of the Environmental Defense Fund.

2 Sun UltraSPARC 2 (200MHz) under Solaris 2.5.1

likely to penetrate the California fuel mix, a more rigorous modeling capability for the overall supply potential of this resource is necessary both to gauge the potential of wind, and to forecast operation of the California market with a significant wind contribution.

Geographic Information System

In this study, a more detailed inventory of the wind potential has been incorporated into the existing Elfin data base, providing a dramatic improvement over the current generic representation. This inventory has been developed in two stages. First, CEC studies conducted in the 1970s and early 1980s of favorable California wind sites were reviewed. These studies not only identify sites but also provide chronological wind data and other useful base information. Second, using GIS[3], these sites have been placed on topographic maps and their proximity to transmission lines and roads calculated. This information yields a more realistic estimate of development costs at the sites, and introduces a previously non-existent spatial element into the Elfin analysis. In simple production costing, possible generation options are represented as generic options that are chosen by the model based either traditionally on cost minimization, or, more recently, on profitability. The options contain no geographic information because any one unit of the generic resource is identical to any other. However, by developing multiple generic options based on actual surveyed sites, whose cost characteristics have been calculated using GIS, not only is the overall representation of the resource more accurate, but GIS also brings a spatial component into the analysis.

This inventory of wind sites has been entered into the Elfin model in the form of multiple generic resources, each representing the wind potential at one of the sites. Elfin capacity expansion runs then choose the viable sites and build wind farms accordingly. The key point to note is that the best wind sites in terms of wind class may not be the ones chosen first, for two reasons: first, the wind pattern may not be coincident with times of high electricity market prices; and second, the sites with good wind speeds may have other characteristics, such as poor transmission access that would make them costly relative to poorer but better-situated resources. In other words, Elfin is presented with a long-run supply curve of wind resources and it finds the level of development justified by the market price, but, because the information on the production and price sides is available, typically every three hours, this supply curve is complex and could not be readily drawn.

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[3] This work was conducted using Arc Info 7.0.4, a proprietary product of Environmental Systems Research Institute (ESRI), run on a Sun UltraSPARC 2 (200MHz) under Solaris 2.5.1.

3. Sites

Previous Site Studies

The California Energy Commission (CEC) funded an extensive series of wind resource assessment studies in the late 1970s and early 1980s.[4] These studies were conducted by various organizations ranging from research organizations, like SRI International, to meteorological consulting firms, to one-time wind generator manufacturers, like Boeing. As a result, the content and quality of the reports vary but the main emphasis in all of them is wind characterization at locations favorable to wind farm development.

The CEC studies do not cover the sites along the coastal mountains of Central California because, at the time, the Bureau of Reclamation of the U.S. Department of the Interior (DOI) was conducting its own wind energy study (DOI 1983).

A summary report by the CEC (Waco et al. 1983) evaluates all the consultant reports including the DOI study for the Central California coastal ranges and identifies Solano and Alameda Counties, the major east-west passes of Southern California (Tehachapi and San Gorgonio passes), and In-Ko-Pah Gorge in eastern San Diego County as the most promising sites with annual average wind speeds greater than 7 m/s (16 mph). Certain ridges below 1 800 m (6 000 ft) along the coastal mountains and the Portal Ridge-Sierra Pelona area in northern Los Angeles County, and several other locations with annual average wind speeds in the range of 6 to 7 m/s (13-16 mph) are also identified.

Based on the CEC studies, 36 sites suitable for development are identified (Table 1). As mentioned above, some of these sites have high average annual wind speeds (greater than 7 m/s). Marginal areas with average annual wind speeds in the range of 6 to 7 m/s are also included in our study set in case the diurnal and seasonal patterns of wind speed at these sites makes them more desirable than their average wind speeds indicate. More detail on the sites appears in Appendix A.

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4 The resource assessment studies covered Northeastern California (Simon et al. 1980), Northwestern California (Ruff et al. 1983), Alameda and Solano Counties (Davis et al. 1980), Southern California Desert (Berry et al. 1981), Southern California (Zambrano et al. 1981), Palm Springs-Whitewater region (Zambrano et al. 1980), and San Diego County (Richmond et al. 1980). Furthermore, the reports that were produced as a result of CEC efforts in this field are not limited to the list presented here.

Table 1. Wind Sites and Numbers Used in This Report Identifying These Sites

Identifier	Site	Site Information[5]
1	Bear River Ridge	(good)
2	Solano Hills	(good)
3	Solano Hills	(marginal)
4	Altamont Pass	(good)
5	Altamont Pass	(marginal)
6	San Gorgonio	Northern Foothills (good)
7	San Gorgonio	Whitewater (good)
8	San Gorgonio	Cabazon (marginal)
9	Tehachapi Pass	Cameron and Oak Ridges (good)
10	Tehachapi Pass	Pejuela Peak (good)
11	Tehachapi Pass	Downslope (marginal)
12	Tehachapi Mountains	La Liebre Ridge (marginal)
13	Barstow	(good)
14	Barstow	(marginal)
15	Mountain Pass	(good)
16	Mountain Pass	Clark Mountains (good)
17	Gorman	Sandberg (marginal)
18	Sierra Pelona	(marginal)
19	Soledad Canyon	(marginal)
20	Portal Ridge	(marginal)
21	Fairmont Reservoir	(good)
22	Santa Catalina	
23	Cajon Pass	(marginal)
24	Cajon Mountain	(good)
25	Strawberry Peak	(marginal)
26	Mt. Laguna	(good)
27	Julian	Vulcan Mountain (good)
28	In-Ko-Pah	Boulder Park (good)
29	In-Ko-Pah	Sugarloaf Mountain (marginal)
30	Table Mountain	(good)
31	Jacumba Mountains	(good)
32	Walker Ridge	(good)
33	Berryessa Peak	(marginal)
34	Potrero Hills	(good)
35	Pacheco Pass	(marginal)
36	Cottonwood Pass	(marginal)

5 *good:* wind speed at 10 m is greater than 6.7 m/s
marginal: wind speed at 10 m is less than 6.7 m/s

Topographical Maps

At the outset, the intention was to develop a list of potential wind sites using data on wind power, roads, transmission data, population data, blackout areas such as federal land, and any other relevant GIS data sets available. Because a number of obstacles obtaining the necessary GIS data sets were encountered, the analysis was limited to the sites identified by the CEC, as described in *Previous Studies*.

Figure 1 shows the 36 sites studied here. The actual site is at the hub of the windmill icon. The figure also shows areas of the state that were identified as possible blackout areas, that is, areas in which wind development may be precluded by special land use restrictions. Not marked are urban areas, which, similarly, are unlikely to prove hospitable to wind farms. This GIS information is not used in this analysis but is shown here to demonstrate how the GIS analysis could be expanded.

We obtained road data by converting an Environmental Systems Research Institute (ESRI) Arcview U.S. road data set (ESRI 1993) into an ArcInfo map, and selecting California roads. Difficulties were experienced obtaining an accurate transmission line map. One of the maps we obtained proved to be unusable because of problems with georeferencing of the original (computer-aided design) CAD file and attaching attribute data. Transmission lines obtained from the Federal Emergency Management Agency (FEMA 1988) were ultimately used. The lines were created by connecting known points in the distribution system of 115-500 kV lines. There is no attribute data associated with the lines. This transmission line map will be replaced by detailed data under development by the CEC. Figure 2 shows the potential wind sites against the roads and transmission lines. GIS was used to estimate proximity of CEC wind sites to roads and transmission lines. These distances serve as the basis for an estimated cost function of wind development.

Data on wind power were obtained from the National Renewable Energy Laboratory (Elliott et al 1986). A map of the wind power classes developed from their data is shown in Figure 3. Wind power classes are used to describe the energy contained in wind, averaged over area and time (Table 2). Areas designated Class 4 or greater are deemed suitable for advanced wind turbine technology under development today. The wind power classes were assigned based on the available windy land and wind electric potential per grid cell (Elliott and Schwartz 1997). Thus, they present a general idea of the wind power in a grid cell.

Figure 1. Potential Wind Sites