

## Chapter 4: Wind

### Summary

Wind power refers to capture of the energy in the movement of air created by thermal differences across the surface of the earth. A wind turbine transforms the kinetic energy of the wind into mechanical or electrical energy that can be harnessed for practical use. Mechanical energy is most commonly used for pumping water in rural or remote locations. Wind electric turbines generate electricity for homes, businesses, and utilities.

Wind technology is proven and has availability rates as high as 98 percent.<sup>1</sup> (Availability rates are the percent of time that a turbine is available to operate.) Additionally, wind turbines and related equipment occupy about 5 percent of the land in a wind farm. The remaining 95 percent of the land in a wind farm can be used for agriculture. Land leases for wind equipment are commonly viewed as economic supplements to agricultural landowners. Although the additional cost of operation makes wind resources slightly more expensive than conventional resources, the overall costs are very competitive. Wind technology is the lowest cost renewable technology, which makes it an economic alternative to carbon-based fuel energy sources.<sup>2</sup> Wind energy is also not subject to volatile conventional fuel prices. The cost of wind-generated electricity is dominated by capital or first costs. In addition, the production of electricity from a wind turbine is not a combustion process. Therefore, it produces no air polluting emissions unlike conventional fossil fuel burning power plants.

*Wind technology is proven and has availability rates as high as 98%.*

The cost of generating energy from wind has dropped significantly in the last 20 years, making wind the fastest growing (on a percentage basis) central station renewable resource generation option. Tax credits and other economic incentives play an important role in the rate and size of wind resource development.

*While there are no significant wind energy systems in the Region now, the results of this study indicate a large technical potential for this source of renewable energy.*

While there are no significant wind energy systems in the Region now, the results of this study indicate a large technical potential for this source of renewable energy and by the end of 2005 50 MW of wind capacity is expected to be developed in the southeast section of the Region in Boulevard. The largest power potential from wind in the spring, summer, and fall occurs in the evening and early morning when the regional load demand is not at its peak. Although the wind resource peak power potential does not coincide with the peak of the regional load demand, wind can still be used to meet some of the Region's energy needs. The gross and technical potential for wind energy and capacity in the Region is shown in Table 4.1.

<sup>1</sup> J. Manwell, J. McGowan, A. Rogers, *Wind Energy Explained: Theory, Design and Application*, (New York, 2002), p. 380.

<sup>2</sup> Moore, Michal, Former Chief Economist at NREL, 2002-2004.

**Table 4.1: Summary of Potential Energy and Capacity in the San Diego Region**

Gross Potential		Technical Potential	
Energy (GWh)	Maximum Capacity (MW)	Energy (GWh)	Maximum Capacity (MW)
21,000 to 24,000	6,500 to 6,900	3,700 – 4,100	1,380 – 1,530

#### 4.1 Total Wind Resource Potential in California

Wind turbines in California generated approximately 3,573 GWh in 2003, and the State has an installed capacity greater than 1800 MW. Currently the Altamont, Tehachapi, and San Geronio high wind areas account for 95 percent of the State's electrical wind power generation. Wind harvested in these three regions also accounts for approximately 11 percent of the world's wind-generated electricity.<sup>3</sup> Table 4.2 includes 2003 wind energy production in California and estimates of the gross and technical potential of wind in California.

*Analysis has revealed that the technical potential for the San Diego region is between 3,700-4,100 GWh/yr and 1,380-1,530 MW.*

The California Energy Commission (CEC) characterizes gross potential as being the potential that is not filtered or does not exclude areas based on variables such as land use, land characteristics and economics. The technical potential takes these variables into account.

**Table 4.2: Summary of Wind Potential in California<sup>3</sup>**

	MW	GWh/yr
<b>Existing Wind Resources (2003)</b>	1,880	3,573
<b>Gross Potential</b>	38,000	120,000
<b>Technical Potential</b>	9,500	31,000

#### 4.2 Wind Resource Potential in the San Diego Region

Wind energy is a prevalent renewable resource in the San Diego region. There are over 600 square miles of Class 3 to Class 7 wind locations within the Region. The development of all of these wind areas equates to a gross energy potential of approximately 21,000 to 24,000 GWh/yr and a maximum potential capacity of 6,500 to 6,800 MW. This is a very large amount of potential renewable energy. However, the majority of this energy and capacity would be very difficult to harvest or develop because of technical, physical, and political constraints. One of the main goals of this wind analysis is to determine the technical potential of the regional wind energy by taking into account these constraints. Analysis has

<sup>3</sup> Yen-Nakafuji, California Energy Commission, *California Wind Resources*, Draft Staff Paper , CEC-500-2005-071-D, April 2005, p.9, 15-20.

revealed that the technical potential for the San Diego region is between 3,700-4,100GWh/yr and 1,380-1,530 MW.

#### 4.2.1 Gross Potential for the San Diego Region by Land Type

The gross energy potential and capacity for the San Diego region (without technical filters) is shown in the ensuing tables by land classification within the San Diego region. These estimations are very broad approximations based on the area and average wind speed for each land classification listed in Table 4.3. The assumptions to determine the gross potential are the following:

- The Weibull Distribution shape parameter (k) equals 2
- The scale parameter (c) was based on the average wind speeds
- Wind speed changes due to terrain roughness are negligible

**Table 4.3: Gross Energy Potential and Average Capacity per Land Classification**

San Diego Region Land Classification	Land Area for Wind Classes 4 to 7 (mi <sup>2</sup> )	Average Capacity Range (MW)	Energy Potential (GWh/yr)
US Forest Service	19.1	117 to 138	1,010 to 1,140
State Park	144.9	892 to 1,020	7,700 to 8,700
Bureau of Land Management	137.9	910 to 1,050	7,700 to 8,900
Privately Owned Land	61	355 to 406	3,150 to 3,530
Indian Reservation	23.9	140 to 158	1,210 to 1,360
State Owned Land	1.3	7 to 10	63 to 74
County of San Diego	3.3	21 to 26	183 to 216
Military	0.2	1 to 2	9 to 11
Other Special Districts	0.6	3 to 6	33 to 39
CalTrans	1	5 to 8	50 to 56
Water Districts	1	5 to 6	49 to 53
Totals (rounded)	394	2,500 to 2,800	21,000 to 24,000

#### 4.2.2 San Diego Region Wind Technical Potential

This section further refines the output of section 4.2.1 to determine the technical potential for load application. Development of the technical potential has been done by applying the

filters described in Section 4.4 and analyzing individual wind site characteristics and topography. Many land categories in Table 4.3 that were described to have significant amounts of gross potential were excluded with the application of the filters.

The San Diego region, after applying the described methodology, has a wind technical potential of 1,350 to 1,530 MW, and 3,700 to 4,100 GWh/yr energy potential for Class 4, 5, 6 and 7 wind sites. The technical potential results are displayed in Table 4.4. Technologies to economically harness Class 3 and lower wind resources are not yet available.

**Table 4.4: Wind Technical Potential in the San Diego Region**

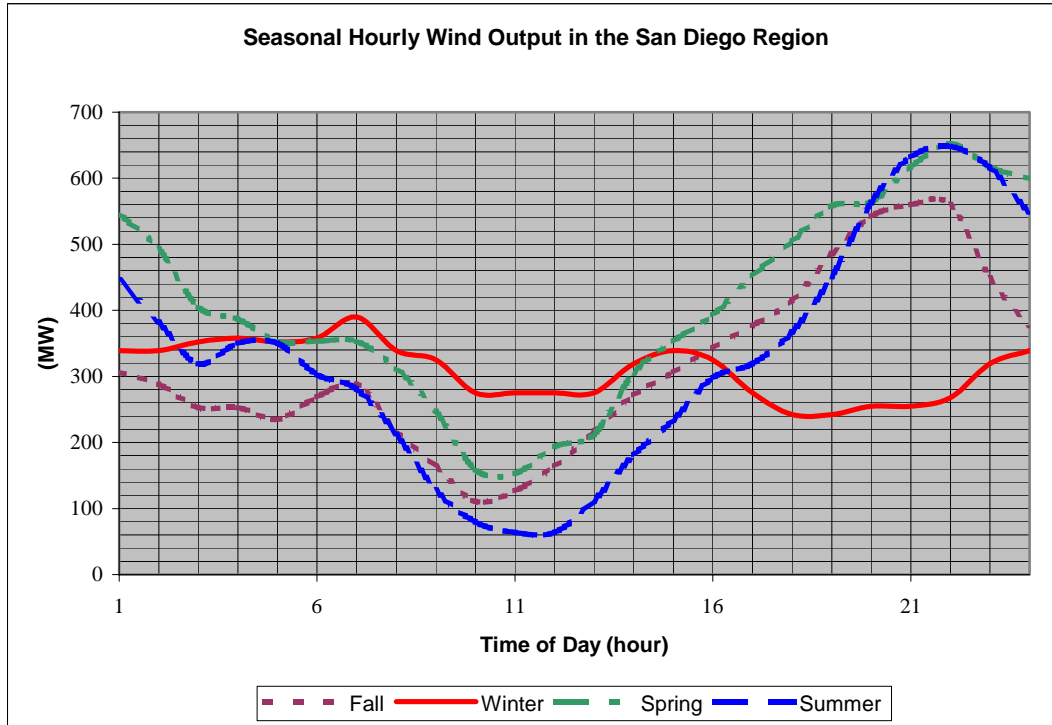
Wind Speed	Capacity (MW)	Potential Energy (GWh/yr)
Total for Class 4, 5, 6 & 7	1,350 to 1,530	3,700 to 4,100

### 4.3 Expected Capacity at System Peak

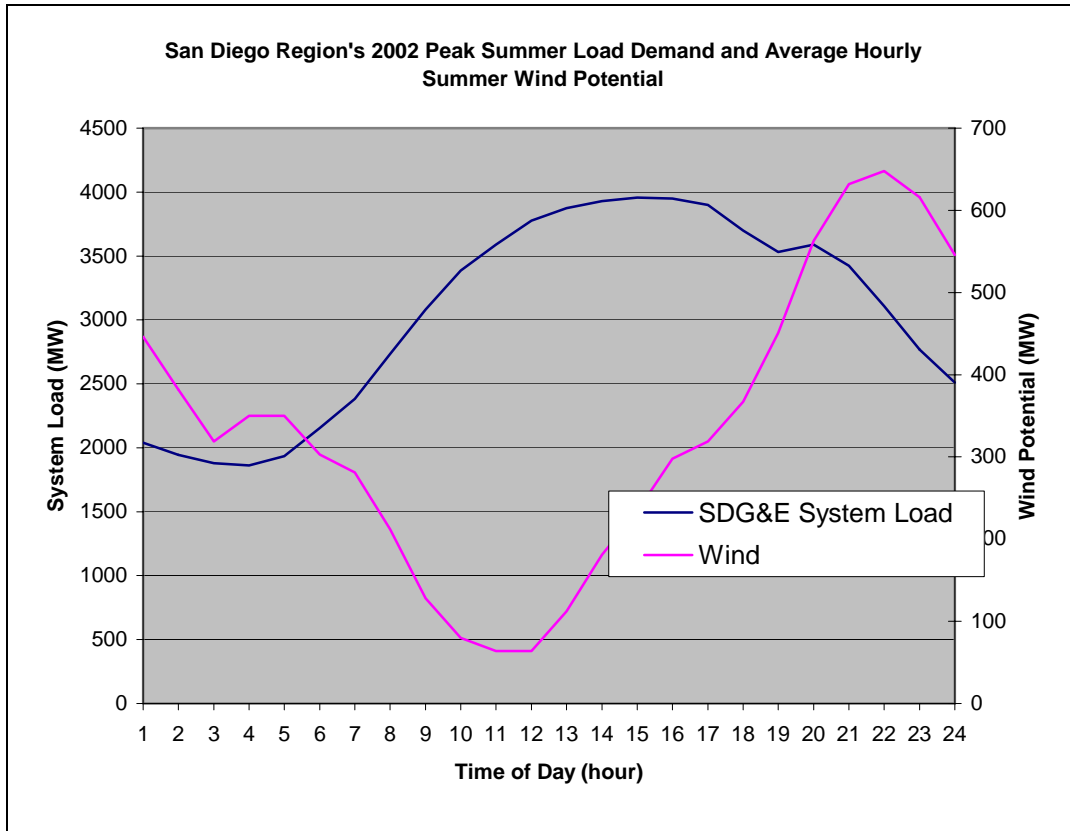
The largest power potential from wind in the spring, summer, and fall typically occurs in the evening and early morning when the regional load demand is not at its peak. Although the wind resource peak power potential does not coincide with the peak of the regional load demand, wind can still be used to meet some of the Region's energy needs. Figure 4.1 illustrates the seasonal hourly wind potential. Appendix F contains graphic displays of the changing wind resource for each month of the year. It should be noted that the winter hourly characteristics are significantly different than the other seasons. The daily peak capacity in the winter is typically not as great as the other seasons, and it does not change as dramatically in a 24-hour period. This may be useful to system operators seeking resources to meet base or intermediate loads. The summer and winter hourly wind potential and the Region's load demand are illustrated in Figures 4.2 and 4.3, respectively.

*It should be noted that the winter hourly characteristics are significantly different than the other seasons.*

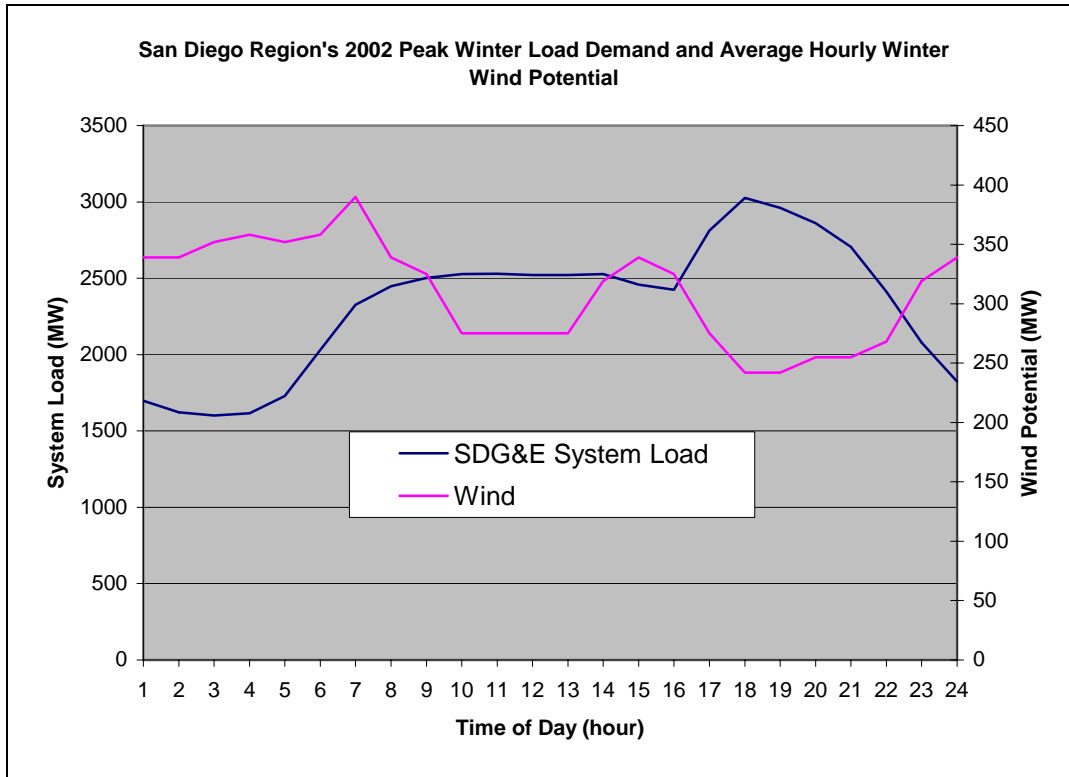
Figure 4.1: Seasonal Hourly Wind Potential in the San Diego Region



**Figure 4.2: The San Diego Region's 2002 Summer Peak Load Demand and Summer Hourly Wind Potential**



**Figure 4.3: The San Diego Region's 2002 Winter Peak Load Demand and Winter Hourly Wind Potential**



#### 4.4 Methodology to Determine Wind Potential

##### 4.4.1 Identification of Windy Locations

The location and area of sites that have a wind speed Class 3 or greater were identified as having wind potential meriting further study. The Study Group identified these sites by creating wind resource maps utilizing GIS data obtained from the CEC and NREL. This data set was originally generated by AWS Truewind Solutions who used computational modeling methods. After the Study Group created the wind resource maps and identified the wind class 3-7 sites, multiple layers of cascading filters were overlaid on the maps. More details are provided in Appendix F section F.2.

##### 4.4.2 Application of Map Filters

The application of the technical filters was designed to reveal potential wind resource locations and to exclude areas that were not practical or feasible for permitting or development. These filters include:

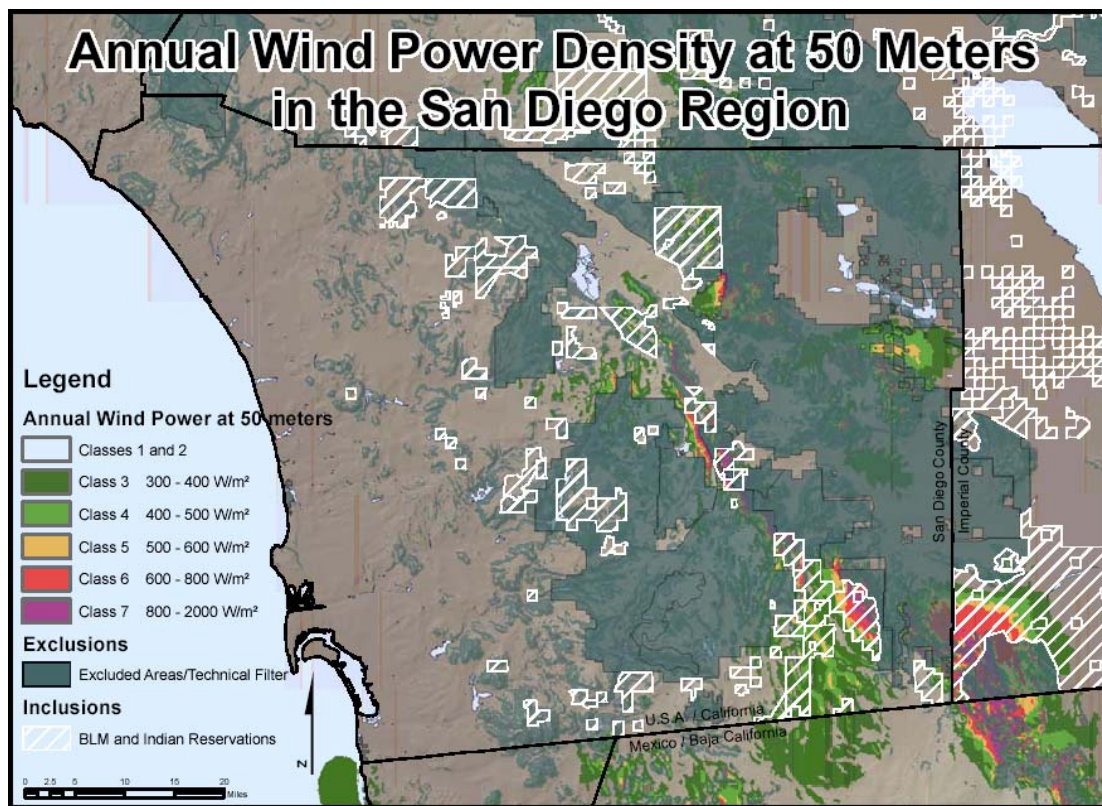
- National parks and monuments
- State parks and recreation
- Bureau of Land Management Wilderness and Wilderness Study Areas
- Grade > 14 percent
- Bodies of water

- Urban Areas
- Locations that are difficult to access such as certain mountain tops and ridges
- Site specific filters

The individual filters listed above were graphically tied together to form a single overlay that is illustrated in Figure 4.4 and is denoted as the “Excluded Areas/Technical Filter”. In addition to the technical filter, other filters were applied in site-specific locations. These site-specific filters were used to exclude certain mountain ridges and terrain that would have a low probability of utility-scale wind turbine installation.

Only land areas that were classified as public domain, Bureau of Land Management (BLM), privately owned lands, or Indian reservations were included in the wind analysis area. This fact does not imply that the included areas: BLM, privately owned land, and Indian reservations will all allow or accept the installation of wind turbines. Rather, these areas were selected because there is a higher possibility of permitting and installation in these land classifications over other land classifications such as state parks and national forests. Figure 4.4 illustrates the public domain BLM areas and Indian reservations after most of the filters have been applied. These areas are identified in the inclusion areas. Privately owned land (which is not indicated in Figure 4.4) was also included in the wind resource potential analysis. (Note: All difficult-accessibility filters and economic filters may not have been applied or illustrated in Figure 4.4).

Figure 4.4: Application of Technical Filters to the San Diego Region’s Wind Areas



### 4.4.3 Calculation Methodology

Once the technical filters were applied to the wind speed resource maps such as Figure 4.4 to locate areas that have high average wind speeds, the characteristics of the wind speed frequencies were used to determine the electrical energy potential for the San Diego region. The wind speed frequencies are the frequency or percentage of occurrence for a particular wind speed and are characterized as a Weibull Distribution. This distribution was used in most facets of the technical potential calculations.

The TRAC<sup>sm</sup> Wind Potential Model developed by Tanaka Research and Consulting was used to determine the technical potential for the Region and the energy per land area for specific sites within the Region. This model takes into account wind speed frequency distribution, wind direction, terrain roughness, availability factors, wind turbine hub height, rotor diameter, and power curve. A representative turbine was selected based on the optimization of annual energy output instead of peak power output or capacity factors. Aerodynamic turbulence, rotor diameters, losses due to the Park Effect, terrain, and predominant direction of the prevailing wind were also used to determine the turbine arrangements and power output per land area. Array losses or the Park Effect creates losses or decreases in electrical production due to aerodynamic turbulence created by the wake of the rotors in a wind farm.<sup>4</sup> The availability factor was assumed to be 98%. Losses due to wind turbine transmission and generation losses and the Park Effect were assumed to be 5 percent each.

### 4.4.4 Application of the Methodology – Monthly Wind Power Maps

The regional wind potential does not remain constant and can change dramatically for each season and month. Figures F.4 to F.15 in Appendix F illustrate these changes and highlight the locations with the highest potential for each month. These figures have the technical filters applied and illustrate the Region's monthly wind power density at 50 meters from the earth's surface.

*The regional wind potential does not remain constant and can change dramatically for each season and month.*

This seasonal variability in the wind resource, coupled with its corresponding hourly variation on a given day, poses a significant challenge to energy planners. However, integrating wind resources into an overall system supply portfolio is already happening in the State, and as more is learned about how best to accomplish this integration, the Study Group believes that increasing amounts of wind power will be developed.

## 4.5 Economics -- Costs of Wind Energy

The cost of generating electricity from wind has dropped significantly in the last 20 years, making wind the fastest growing (on a percentage basis) central station renewable resource for power generation. Further cost reductions are expected to result from efficiency improvements, taller hub heights, larger rotors, advances in electronics, and additional experience operating large wind projects.<sup>5</sup>

New state-of-the-art wind power plants can generate electricity for less than 5 cents/kWh. The most important factors in determining the cost of wind-generated electricity from a wind farm are: (1) the size of the wind farm; (2) the average (as opposed to peak) wind speed at the

<sup>4</sup> J. Manwell, J. McGowan, A. Rogers, *Wind Energy Explained: Theory, Design and Application*, (New York, 2002), p. 384.

<sup>5</sup> Moore, Michal, Former Chief Economist at NREL, 2002-2004.

site; (3) the cost of installing the turbines; and 4) access to transmission lines. Each of these factors will have a major impact on project debt and operating costs. In general, larger wind farms that have a high average wind speed and a geography that does not require an overly complex and expensive installation can produce lower priced electricity.<sup>6</sup>

The cost of wind energy fluctuates depending on many variables such as the availability and amount of subsidies such as a production tax credit (PTC). The cost of wind energy in 2004 averaged 3.5 to 5.5 cents/kwh unsubsidized at a class 4 windsite and further reductions in cost are expected.<sup>7</sup> The current PTC provides a credit of 1.8 cents per kwh and has been extended to December 31, 2005.<sup>8</sup>

#### 4.5.1 Commercial Availability

Onshore wind turbines are widely available and technical refinements are ongoing. Activity in this area includes developing turbine technology that can harvest wind in locations where average wind speeds have been too low to be cost effective.

### 4.6 Issues and Barriers

#### 4.6.1 Dispatchability

The dispatchability of wind power faces unique challenges when compared to conventional power plants. The variable nature of wind limits the on-demand dispatch of power generated from wind. The power generated from wind, however, can be integrated into the dispatching process with careful planning and can be improved by increasing the accuracy of wind forecasting. The transfer of meteorological data to the dispatcher would also help to limit imbalances. It should also be noted that wind power can provide potential benefits in regard to transmission dispatch and congestion. Analysis is currently underway by the CEC and others involved in the wind industry to study the strategic placement of wind turbines in an attempt to alleviate transmission congestion.

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#### 4.6.2 Environmental

The visual impact of wind turbines or wind farms is of high concern for communities in the United States. It is difficult to achieve a consensus or solution for this concern because visual impact is difficult to quantify and is based on a wide range of subjective opinions. A segment of the public views wind turbines as ugly machinery that visually pollutes the landscape, while another views it positively as a source of energy that produces no air pollution emissions and is not dependent on fossil fuels. Therefore, the visual impact is difficult and challenging to address. Wind energy planners and developers address this impact by placing significant emphasis on the visual composition of wind farm locations by addressing elements such as visual clarity, harmony, balance, focus, order, and hierarchy to mitigate visual impacts.<sup>9</sup>

<sup>6</sup> Moore, Michal, Former Chief Economist at NREL, 2002-2004.

<sup>7</sup> S. Butterfield, Briefing for the San Diego Regional Renewable Study Group. NREL, National Wind Technology Center, Golden Colorado. October 5, 2004.

<sup>8</sup> American Wind Energy Association (AWEA) <http://www.awea.org/policy> This site was last accessed June 2005.

<sup>9</sup> J. Manwell, J. McGowan, A. Rogers, *Wind Energy Explained: Theory, Design and Application*, (New York, 2002), p. 476-480.

The noise impact of wind turbines is also determined subjectively, but it does have quantifiable properties (sound level and frequency) that can be measured and mitigated. The audible impact from a wind farm often seems greater when located in more natural areas with fewer surrounding industrial sounds or background noise to mask the wind turbine sounds. However improvements in wind turbine design have resulted in lower noise decibel levels.<sup>10</sup>

The influence of wind turbines on birds and bats has been researched and discussed extensively, but the impact is still unclear. It is uncertain how wind turbines affect their mortality rates, habitat, and migration passages.

#### 4.6.3 Land Utilization

Certain land classifications have typically not been acceptable or available for wind farm siting. However, land areas designated as Bureau of Land Management (BLM), Indian reservations, and privately owned land have had wind development. This serves as the precedent or example of land classifications that may allow wind farm development. Another issue or barrier for potential wind farm locations is that some sites are located in remote locations making personnel access and transmission line installation difficult.

#### 4.6.4 Transmission Access

Although wind potential exists within the San Diego study area, access to appropriate transmission lines and substations is one of the most challenging hurdles to overcome to make wind development economically viable. Some of the largest wind resource areas (near Interstate 8) in the San Diego region have a 500 kV transmission line nearby.

*Although wind potential exists within the San Diego study area, access to appropriate transmission lines and substations is one of the most challenging hurdles to overcome to make wind development economically viable.*

#### 4.6.5 Maintenance

Utility-scale wind turbines have been improved to be more reliable and require only a small percentage of time off-line for maintenance. Modern utility-scale wind turbines are available to operate 98 percent of the time.<sup>11</sup>

#### 4.6.6 Legislation and Regulatory

The availability of a production tax credit (PTC) is strongly correlated with the amount of wind energy development. The PTC has helped to make electricity generated by wind cost competitive and has helped to promote wind farm development. The volatility of the PTC or threats of loss of the PTC, however, does create uncertainty for wind energy development.

<sup>10</sup> J. Manwell, J. McGowan, A. Rogers, *Wind Energy Explained: Theory, Design and Application*, (New York, 2002), p. 481-492.

<sup>11</sup> J. Manwell, J. McGowan, A. Rogers, *Wind Energy Explained: Theory, Design and Application*, (New York, 2002), p. 380.