Wind and the Grid

As the wind turbines spin on the Altamont Pass near Livermore, residents of the area and travelers passing through get a first-hand look at technology that turns wind power into usable energy. In California, wind generates about 2 percent of the electricity produced by renewable resources, which account for 11 percent of the state's annual energy production. By 2020, the state government wants to increase production from these cleaner, "greener" energy sources to 33 percent of the total power supply. In doing so, the annual production from wind sources would increase from 2,300 megawatts to between 12,000 and 15,000 megawatts. To meet this aggressive goal, the power industry must overcome the challenges associated with integrating wind into the nation's electrical infrastructure, known as the grid.

Wind is intermittent, and changes in the weather affect it on a seasonal, daily, and minute-to-minute basis. Even when winds are strong, the amount of electricity produced by turbine farms varies as conditions change. Because of this variability, electrical grid operators have difficulty establishing schedules to harness wind energy in the amounts needed to meet demand. In addition, sites for large, tall wind turbines must be carefully selected to minimize environmental effects, for example, to protect avian species.

Research engineer Dora Yen-Nakafuji in Livermore's Engineering Directorate is working with utility companies, the power industry, state and federal agencies, and other organizations to address these wind-related energy issues. As part of this effort, she is characterizing the complex interactions that affect wind resources and helping industries develop new technologies for integrating wind energy into the grid.

For the last several years, Yen-Nakafuji and colleagues in the Engineering, Physical and Life Sciences, and Computation directorates have focused on using the Laboratory's modeling and computational expertise to refine wind-forecasting tools. In particular, they want to identify sources in the various models that lead to forecasting error—the difference between predicted wind conditions and those that actually occur. Reducing such errors will provide grid operators with the data they need to reliably determine the output of wind generators and more effectively manage the electrical grid.

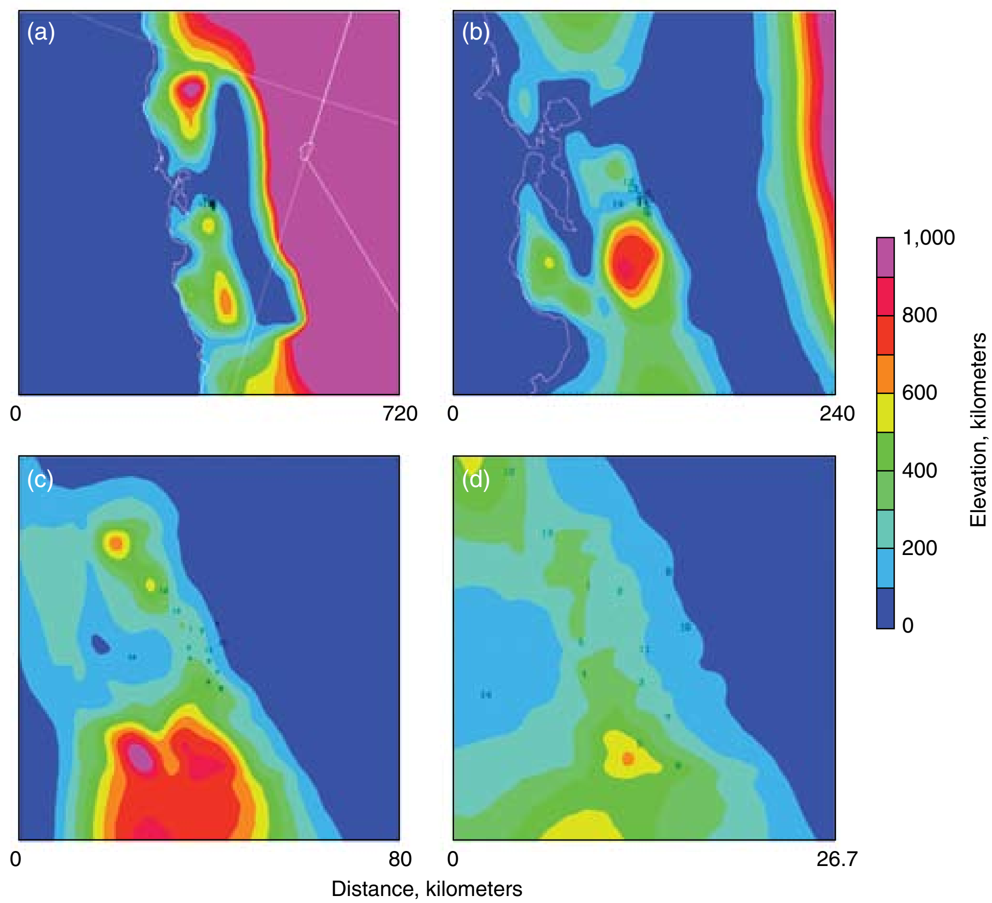
California's Impetus

Approximately half of the states in the U.S., including California, have established standards requiring electrical companies to increase renewable energy production by a certain percentage within a specified period. The California standard, originally passed by the state Senate in 2002, mandates a 20-percent increase in renewable energy production by 2010 with an accelerated target of 33 percent by 2020. In addition, state Assembly Bill 32, passed in 2006, requires a 25-percent reduction in greenhouse-gas emissions in the same time frame. Together, these two bills are a major impetus for California's move toward alternative and renewable energy resources.

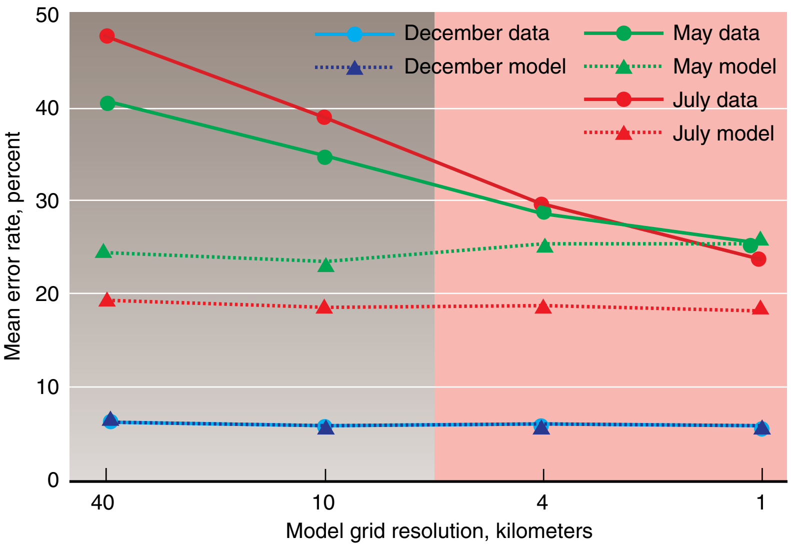
From 2001 through April 2007, Yen-Nakafuji worked with the California Energy Commission (CEC) to meet the goals outlined in the state mandates. During that time, she helped improve wind forecasting by more accurately characterizing the meteorology in California wind corridors, which feature hilly topography and a mix of marine and inland climates. As part of CEC's California Regional Wind Energy Forecasting System Development initiative, Yen-Nakafuji and other Laboratory experts used higher-resolution weather prediction models to better simulate wind characteristics, such as speed and direction.

To create wind-energy forecasts for utility schedulers and operators, industry forecasters input regional and site-specific data gathered from ground sensors and newer remote-sensing devices, such as sonic detection and ranging systems and Doppler radars, to augment standard weather models. Standard forecasts provided by the National Weather Service and other organizations typically cover large land areas tens to hundreds of kilometers wide. Livermore researchers at the National Atmospheric Release Advisory Center have developed higher-resolution models that simulate airflow over smaller areas. Improved grid resolution would likewise improve the accuracy of wind-energy forecasting models. Such changes, however, increase the computing time required for simulations to run and, thus, the associated costs.

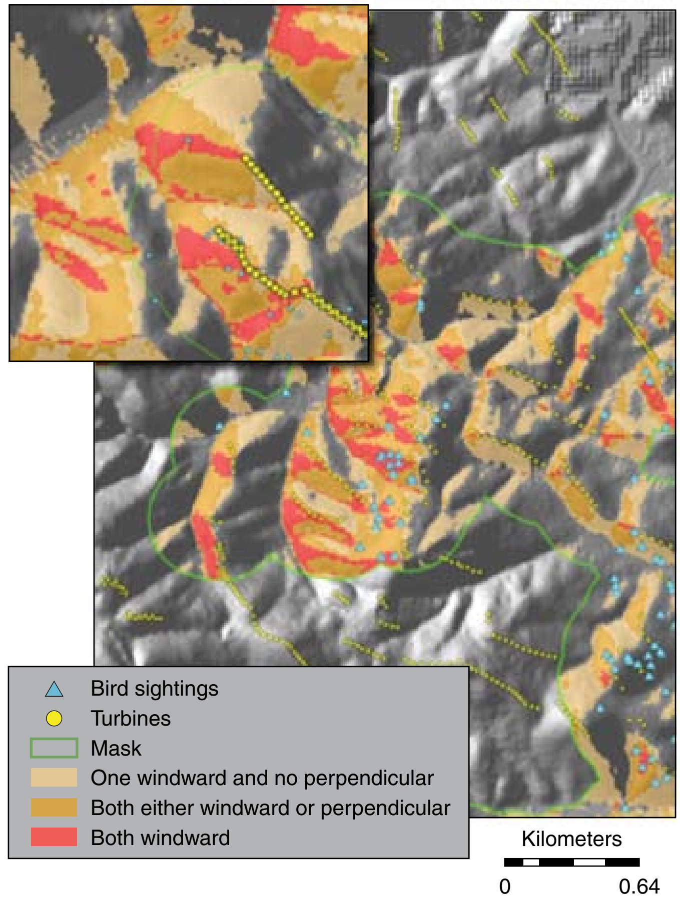
To balance the error rate and computational efficiency, Yen-Nakafuji and her colleague Steve Chin compared simulations with resolutions from 40 to 0.44 kilometers and determined the optimal threshold for grid resolution. Their study also indicated that during summer, variations in meteorological conditions increase the forecasting error rate. Thus, using an improved grid resolution in the summer is especially important for forecasting accuracy.



These computational models, developed by the Laboratory's National Atmospheric Release Advisory Center, have grid resolutions ranging from (a) 12, (b) 4, (c) 1.33, and (d) 0.44 kilometers. As resolution improves, more information becomes available on the wind density in an area, as indicated by the color-coded resolved terrain.



A comparison of modeling results with observational data shows how grid resolution affects the error rate in wind-energy forecasts. The forecasting error is higher in the summer months when meteorological conditions are more variable. Improving grid resolution will significantly increase the accuracy of forecasts during those months.



Data on wind conditions superimposed on topographic data of the Altamont Pass near Livermore show where wind turbines are located in relation to bird sightings. Terrain highlighted in red indicates high-usage areas, where birds are active year-round.

Yen-Nakafuji also worked with the Laboratory's geographical information system (GIS) experts to evaluate sites for wind turbines and mitigate environmental effects of new wind facilities. Using observational data compiled by CEC and the National Renewable Energy Laboratory, the research team showed how placement of wind turbines on the Altamont Pass could reduce harm to birds in the area. Research conducted by CEC linked statistical data on bird activities and behavior to the regional terrain. "That observational study took six years to cover only one-third of the Altamont," says Yen-Nakafuji. "We needed to find a quicker method for evaluating the rest of the area."

Using GIS analysis and rendering tools, the team linked the avian behavioral data from the CEC study to the terrain that various species fly over. The GIS analysis provided details such as flight patterns and timing, terrain gradients, and wind direction. The overall visual representation showed where turbines are located relative to bird sightings. The Livermore team's research indicated that moving turbines away from the high-usage areas would reduce the risk to avian species in the area. This analysis capability is now part of a CEC-sponsored Web-based Renewable Energy Portal, which was developed to aid industry and the public in tracking, trending, and monitoring wind-energy resources.

Inspiring Confidence

In 2008, with funding through the Business Development Counsel in Livermore's Global Security Principal Directorate, Yen-Nakafuji began the National Transmission and Energy Resilience Response Analysis (N-TERRA) initiative to respond to national and regional needs for grid transformation and renewable integration. Under N-TERRA, Yen-Nakafuji assessed not only the reliability and sustainability of wind-energy resources but also the potential vulnerabilities associated with integrating intermittent renewables into the electrical infrastructure.

Out of this initiative grew Wind SENSE, a program funded by the Department of Energy's Office of Energy Efficiency and Renewable Energy. Wind SENSE combines the Laboratory's advanced computing capabilities with field data from meteorological towers and other sensors as well as performance data from turbine farms to develop an integrated wind-forecasting tool for grid operators. "The goal of Wind SENSE is to provide control room operators with an awareness, or 'sense,' of the wind conditions and energy forecasts in their native operating environments," says Yen-Nakafuji. A reliable forecasting tool will increase operator confidence in the availability of wind resources when managing the electrical infrastructure.

Through this program, Yen-Nakafuji and her team are working with industries to selectively input data from wind turbine sites into mesoscale models and develop more accurate wind forecasts. "With the information we collect, we can optimize the placement of sensors upwind and downwind of a resource area," says Yen-Nakafuji. The team can then work with utility operators to generate forecasts 48, 24, and 1 to 3 hours ahead of scheduling times. The team's next step is to develop a mechanism for integrating this tool into control rooms.

The team is also applying the Laboratory's expertise in analyzing large-volume data sets to improve wind forecasts. "So much information is available, no one person could possibly make sense of all the data," says Yen-Nakafuji. Overall, the Laboratory's contributions are providing industry with the tools needed to ensure that the current infrastructure can reliably accommodate intermittent wind resources.

Climate Change and Future Needs

Global changes in climate could have an enormous effect on the output of all renewable energy sources. For example, increases in atmospheric pressure could alter regional wind patterns, or greenhouse-gas emissions may impede production of solar-generated power. According to Yen-Nakafuji, "Livermore is working with utility partners and leading the initial effort to gauge potential climate impacts on electricity generation by weather-dependent renewable resources."

Global-scale climate models can simulate temperature, pressure, and precipitation changes in addition to other environmental parameters. Typically, these models examine potential changes over the next 50 to 100 years. However, utilities are planning infrastructure to support renewables in the next 3 to 5 years. Using data from climate studies, such as the work performed by the Intergovernmental Panel on Climate Change, the Laboratory is developing computational models to forecast environmental conditions within a shorter time frame. These assessments may provide better insight into how climate change could affect renewable energy sources over the long term and thus future investments in renewables. As an example, if models predict significant decreases in rainfall over the next 20 years, hydroelectric dams may generate less energy than they do today. Plans for the future infrastructure must accommodate these changes to ensure that the electrical grid continues to meet demand.

Hydro, solar, and wind resources could play a vital role in the nation's future energy production. Working together, the Laboratory, utilities, and the power sector are improving capabilities to integrate these cleaner sources of energy into the grid. As a result, the Laboratory is helping California serve as an example to other states, moving the nation one step closer to reliable, renewable energy and a healthier environment.

—Caryn Meissner

Key Words: climate change, electrical grid, electrical infrastructure, intermittent renewables, National Transmission and Energy Resilience Response Analysis (N-TERRA), renewable energy, wind forecasting, Wind SENSE.

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