ESIG
ENERGY SYSTEMS INTEGRATION GROUP

ESIG REPORT

# Weather Dataset Needs for Planning and Analyzing Modern Power Systems

## EXECUTIVE SUMMARY

The electricity system is rapidly transitioning from a system mostly powered by fossil fuels to one in which wind, solar, hydro, and nuclear generators provide most of the generating capacity and energy. At the same time, energy-limited resources such as battery storage are rapidly becoming more prevalent, and behind-the-meter generation is blurring the lines between generation and load and between transmission and distribution. Concurrently, load is fundamentally changing as transportation and heating electrify. These widespread changes lead to the increasing weather-dependence of supply and demand, making power system planning dramatically more complex and requiring much more comprehensive weather data for robust system planning.

The Energy Systems Integration Group convened a project team to assess the gaps in existing weather data used in power system planning and outline a process for producing ideal weather datasets for planning studies for increasingly weather-dependent electric power systems of the future. The report provides details on what is needed and why, outlines the status of and gaps in existing data and methods, and describes an approach to building a solid, long-term solution.

### Increasing Weather Dependence and Weather Complexity

The electric power system has always been affected by the weather. Demand has long been modulated by

**See the full report: Weather Dataset Needs for Planning and Analyzing Modern Power Systems.**

weather conditions, temperature in particular, which also impacts thermal generator capacity (especially gas turbines), cooling water availability, and transmission capacity. Hydro power is obviously impacted by the environmental water cycle. All types of extreme weather impact generators, fuel supplies, and transmission and distribution infrastructure. Going forward, available generation will increasingly be defined by the weather occurring at the location of every wind or solar plant. The behavior in time and space of multiple weather variables—in particular, temperature, wind, and solar irradiance—increasingly affects the amount of generation possible.

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The result is a much greater range of possible outcomes for supply and demand, as they will be driven by the behavior of multiple variables in time and space, as opposed to largely temperature impacts on large load centers. Often, between 10 and 40 years or even more of weather data are needed to capture this range. To robustly quantify the range and probability of possible supply/demand combinations in future planning scenarios requires long time series of temporally coincident weather variables that accurately describe the frequency distribution and evolution of all the weather impacts concurrently affecting the electricity system.

## Accounting for the Increased Weather Dependence and Complexity in Power System Models

Power system planners' efforts to develop resource portfolios that are cost-effective, reliable, and resilient require accurate estimates of increasingly weather-dependent generation and load. Although the use of weather observations would be ideal, this is not practical, and a modeling methodology must be used to synthesize the time series evolution of the necessary variables as accurately as possible. Planners study the power system with a variety of models that can simulate the operation of existing and hypothetical power systems, determine optimal capacity build-outs, and assess resource adequacy, which measures the probability or likelihood of a power system having insufficient resources to meet load. To evaluate a system's dependence on weather, power system models require highly detailed weather data including the key variables influencing solar, wind, traditional generation, transmission, and load.

While in the past, the impact of temperature on demand was by far the biggest weather driver, these relationships are changing. The electrification of transportation and heating are making the end-use loads more susceptible to weather extremes, especially in winter. In addition, as the energy transition proceeds, data for wind speed and solar irradiance are critical for defining wind and solar generation patterns. Increasing weather dependence and complexity also mean that weather associated with outages and derating for transmission and all generation types can cause common mode failures that dramatically amplify weather impacts.

The need for appropriate weather data to study and plan for these impacts is becoming acute.

## A Need for Much Higher Fidelity Weather Data That Meet Several Important Criteria

The most pressing need is to be able to estimate the supply of wind and solar generation in current and future resource portfolios. This requires that the weather driving these generators is accurately quantified at every plausible location where such generators exist or may be built, including customer-sited generation behind the meter. In addition, the data must represent the chronological evolution of weather variables in order to model and optimize the charge and discharge of energy storage.

While weather modeling of the power system has improved considerably in the last several years, there are still major gaps and inaccuracies in the data available to power system planners. Planners lack the necessary information to properly quantify and mitigate reliability risks for power systems transitioning to a fundamentally new resource mix.

**TABLE ES-1**
## The Main Attributes of Time Series Data Necessary to Meet General Power System Modeling Needs

| | |
|---|---|
| **Including the necessary variables** | Include the necessary variables at sufficient spatio-temporal resolution and accuracy to reflect actual conditions that define the generation potential at current and future wind/solar sites and temperature at load centers |
| **Covering multiple decades with ongoing extension** | Cover multiple decades with consistent methodology and be extended on an ongoing basis to capture the most recent conditions and allow climate trends to be identified |
| **Coincident and physically consistent** | Are coincident and physically consistent, in space and time, across weather variables |
| **Validated** | Are validated against real conditions with uncertainty quantified |
| **Documented** | Are documented transparently and in detail, including limitations and a guide for usage |
| **Periodically refreshed** | Are periodically refreshed to account for scientific and technological advancements |
| **Available and accessible** | Publicly available, expertly curated, and easily accessible |

Source: Energy Systems Integration Group.

No currently available datasets meet all the above criteria for power system studies in U.S. geography. The National Renewable Energy Laboratory (NREL) Wind Integration National Database (WIND) Toolkit meets some of the criteria for wind generation estimates, and the NREL National Solar Radiation Database (NSRDB) meets some of them for solar generation estimates. Together these provide the rudimentary datasets that power system modelers are typically using today, but this approach is not a tenable solution looking ahead.

ESIG's report *Weather Dataset Needs for Planning and Analyzing Modern Power Systems* provides details on what is needed and why, outlines the status of and gaps in existing data and methods, and describes an approach to building a solid, long-term solution (Table ES-1). The work required is not trivial, but it is manageable and is much less costly than blindly building trillions of dollars of infrastructure without the basic tools to cost-effectively optimize it and assess its reliability. Continental-scale multi-decadal assessments are becoming more commonplace, particularly over Europe (e.g., through academic institutions or interactive climate services), and some of these tools have global modeling capabilities for renewable system components. However, none of these assessments meet all of the above requirements either (primarily due to inadequate resolution and insufficient validation).

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## Disconnect Between the Power System Modeling and Meteorology Communities

The processes that drive weather involve complex interactions of many variables, especially phenomena such as local circulations that impact wind generation and cloud and aerosol (including smoke) processes that impact solar generation. The number of observations that would be needed to accurately describe the factors defining the amount of generation in different renewable energy portfolios is orders of magnitude higher than what is currently available or realistically possible. Fortunately, the atmosphere follows physical laws, and, using the available observations and sophisticated computer programs that model the laws governing atmospheric processes, it is possible to fill in many of the data gaps.

Weather model output, however, has limitations. All too often, synthetic weather data produced by these models are either used in power system modeling as if they are equivalent to high-quality observations, or, on the other end of the scale, model output is rejected in favor of simpler, easier-to-understand observational records that are then extrapolated using statistical methods with dubious scientific basis. Both outcomes lead to study results that have greater uncertainty than is typically advertised and may result in poor downstream decisions when model-synthesized data that "seem reasonable" are assumed to accurately reflect actual present or future conditions.

For this reason, when significant amounts of weather-driven renewable resources are being evaluated, power system analysis needs to involve meteorologists with an understanding of power systems, who can advise on the best meteorological data sources to use for a task, shine light on the possible biases and uncertainties that these choices will produce, and work together with power system modelers to refine both meteorological modeling and power system modeling codes and processes to provide the most effective coupling between the two. Although cross-sector engagement is increasing, and many meteorologists are now working on energy transition research problems, the level of engagement is still too low. There is a need for more direct engagement by the meteorology community in the energy sector, with the meteorology and power system communities working together and each learning about the needs, constraints, and capabilities of the other field.

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## Poor Data Validation and a Lack of Sector Cooperation

Power system models' reliance on synthesized weather data makes it critical to have confidence in these underlying data—and to understand their limitations and uncertainties—so that the resultant power system analyses can be trusted and their reliability quantified. Confidence is developed by validating and quantifying the uncertainty of the synthetic data, a process that compares the model data to as many ground truth observations as possible, across as much time and space as possible. However, few observations exist for the validation process.

To assess the quality of synthesized data, it is critical that all available observations are utilized. This may mean installing some new observation stations in places where wind and solar are likely to be deployed, but the most obvious and cheapest solution is to make the thousands of observations now available at existing (and future) wind and solar plants generally available. Keeping data proprietary is counterproductive to promoting a transition to wind and solar generation and must change to enable more accurate system modeling, including a better understanding of the accuracy and uncertainty of synthetic time series of weather data. As counterintuitive as it may seem, it is highly likely that time series generation estimates for periods in the past that are being used for power system planning models are of considerably *lower* quality than the time series forecasts of generation produced for operations a day or two in advance of the time they are estimating. This is a direct consequence of the lack of validation and data sharing.

## Climate Change Adds More Degrees of Freedom

In the near term—certainly the next five years, but likely the next one to two decades—the overall impact of

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climate change on the accuracy of power system studies will be small relative to the enormous effect of increasingly weather-driven capacity, energy-limited resources, and electrification.

The impact of climate change cannot be ignored, however, as it is likely to have increasing impacts on the power grid, including temperature-driven record loads and impacts on transmission and generation driven by more extreme and/or frequent weather and climate events. If climate extremes combine with common mode failures because, for example, temperatures fall outside of those typically experienced by the grid, the impacts could be profound. However, in this report the focus is on delivering tangible information about modeling the distribution of coincident weather outcomes on grids with increasing levels of wind and solar. These data are based upon real observations of the atmosphere in which the gaps between observations have been filled by meteorological models that produce results that are physically consistent with the initial observations and internally consistent across weather variables.

Long time series produced in this way (especially if they are extended in an ongoing fashion) will reveal emerging climate trends. However, predicting the future climate requires a different approach with much more uncertainty, not just in the modeling, but (among other things) in assumptions about emissions pathways. The report includes a short section that discusses the key caveats of climate change on the report's central concerns and, as appropriate throughout, notes how climate change could impact its conclusions. It also introduces some of the work and techniques being undertaken in the area of climate change impacts on power systems. A deeper treatment of this topic is recommended for a future task force.

## A Roadmap for Meeting Weather Input Needs in Power System Modeling

There is an urgent need to develop one or more datasets that can become the standard for the power/electricity sector to use now, and moving forward for the foreseeable future, as weather inputs to planning studies including renewable energy integration studies, resource adequacy assessments, capacity expansion planning, and integrated resource planning. Thoughtfully produced, archived, and curated, such data would also be valuable in other important tasks associated with the power system, including renewable energy resource assessments and renewable energy performance analyses, as well as being extremely useful for foundational research work to examine the relationships between supply and demand and weather patterns/climate signals, and for establishing possible climate trends.

There can be no reliable energy transition without broadly available, consistent, weather datasets for power system studies that meet the criteria outlined above. Given public policies that promote or require increases in renewable energy, the necessary data can be considered a public good—one that is government funded, publicly available, and routinely maintained.

There are two stages in the development of an ideal weather dataset.

### STAGE 1: Validate and Refine Requirements and Confirm Need and Fitness

The initial stage of building an ideal weather dataset would convene a technical review committee composed of expert power system stakeholders, experienced energy

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meteorologists familiar with how power system modeling is performed for both hypothetical studies and actual utility or system planning, experienced numerical weather prediction (NWP) modelers whose experience covers high-resolution modeling and data assimilation, and experts in NWP post-processing methodologies including bias correction and downscaling techniques employing machine learning techniques.

The technical review committee would vet and refine the dataset requirements; determine possible methods to create the sample datasets; using three to seven candidate methods, produce sample datasets; and determine whether the candidate datasets add value over the controls. It would select the method with the best combination of cost and accuracy and move to Stage 2.

### STAGE 2: Produce Historical Archive and Ongoing Process

Once the value of a dedicated process to produce a high-fidelity archive is established, the next step is to build the archive and operationalize the process of ongoing extension using the method selected in Stage 1. The main decisions would be how far the archive will go back and when operational extension will be performed; the rest of the process of developing the data should be relatively straightforward and automated.

At this stage, curation of the data will be key to its usability and to understanding its limitations and uncertainty. The following issues would need to be thought through:

- How to ensure that users can efficiently access the data they need
- Building out of a broad observation network to be used in properly validating high-resolution output, in data assimilation where NWP-based solutions are deployed, and in post-processing to reduce systematic errors
- Ongoing validation
- User education
- Documentation of alternative data sources

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With rising levels of wind, solar, and storage and increased electrification, power system planning is becoming more complex and more weather-dependent—with a greater need to accurately model the impacts of weather variables on resource adequacy and system reliability. Accurate power system analysis requires time series data for key weather variables that are temporally coincident, have sufficiently high spatial and temporal resolution, and are robustly validated. The availability of such an ideal weather dataset, together with education and coordination between the meteorology and power system communities, will equip system planners to guide future resource siting and build-out for a reliable, high-renewables grid.



*Weather Dataset Needs for Planning and Analyzing Modern Power Systems* by the Energy Systems Integration Group's Weather Datasets Project Team is available at https://www.esig.energy/weather-data-for-power-system-planning.

To learn more about the weather data needs for system planning with increasingly weather-dependent supply and demand, please send an email to info@esig.energy.



The Energy Systems Integration Group is a nonprofit organization that marshals the expertise of the electricity industry's technical community to support grid transformation and energy systems integration and operation. Additional information is available at https://www.esig.energy.