An Introduction to Wind and Solar Power Forecasting

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Learning Objectives

- Recognize how wind and solar forecasting enhances power system operations
- Understand how wind and solar forecasts are produced
- Distinguish approaches to implementing forecasting systems and collecting necessary data
- Identify policy and other actions to support the implementation of forecasting systems

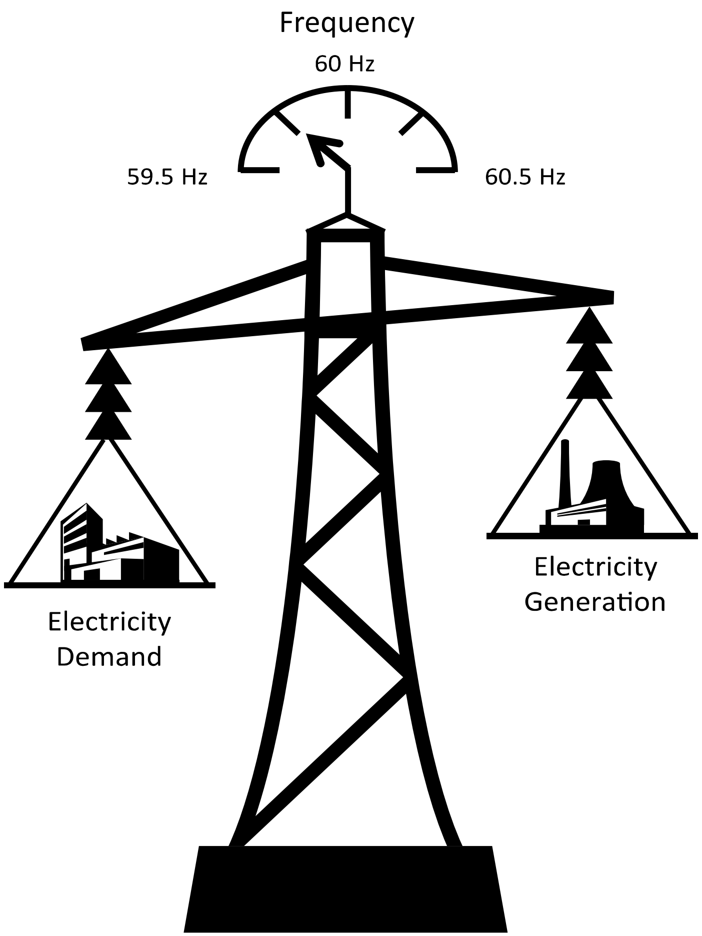
POWER SYSTEM BASICS

Power System Objective

Supply electric power to customers

- Reliably
- Economically

Consumption and production must be ***balanced*** ***<u>continuously</u> and <u>instantaneously</u>***



Maintaining system frequency is one of the fundamental drivers of power system reliability

Slide credit: B. Kirby

Integrating Variable Renewable Energy (VRE) Increases Variability and Uncertainty

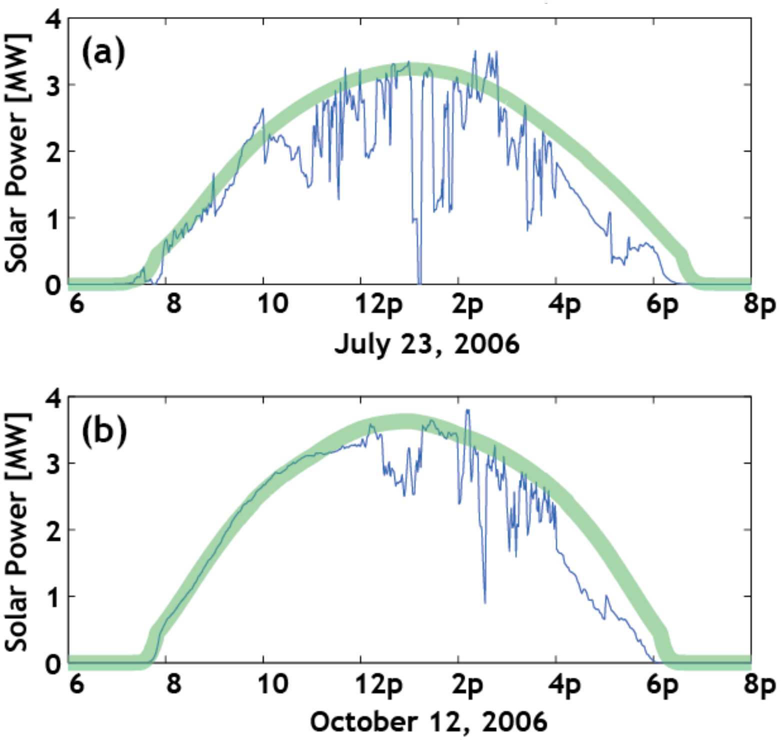
All power systems (regardless of VRE penetration)

- **Variability:** Load varies throughout the day, conventional generation can often deviate from schedules
- **Uncertainty:** Contingencies are unexpected, load forecast errors are unexpected

Wind and solar generation

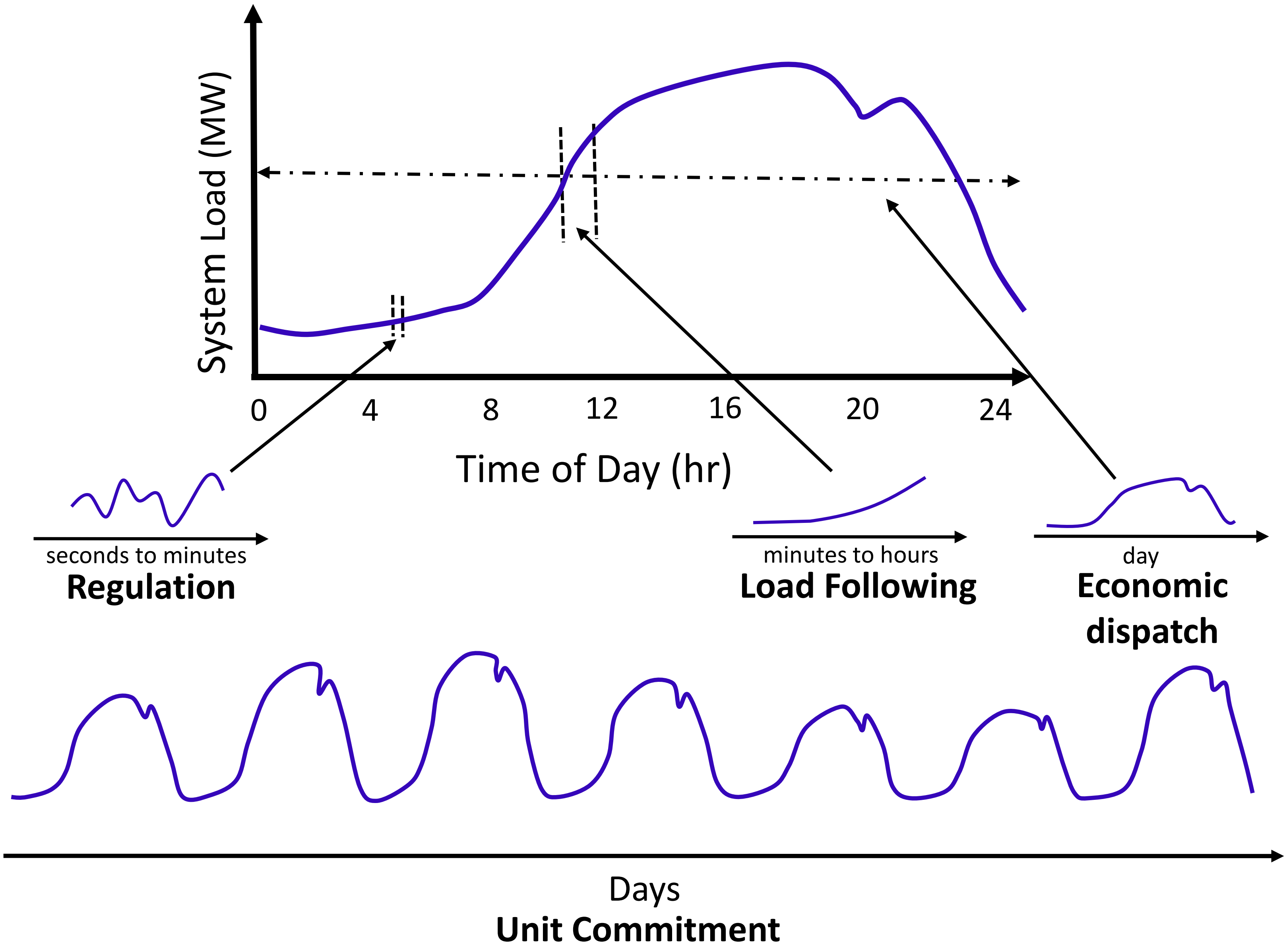
- **Variability:** Wind and solar generator outputs vary on different time scales based on the intensity of their energy sources (wind and sun)
- **Uncertainty:** Wind and solar generation cannot be predicted with perfect accuracy

Output from a 5MW fixed panel in Gujarat, India

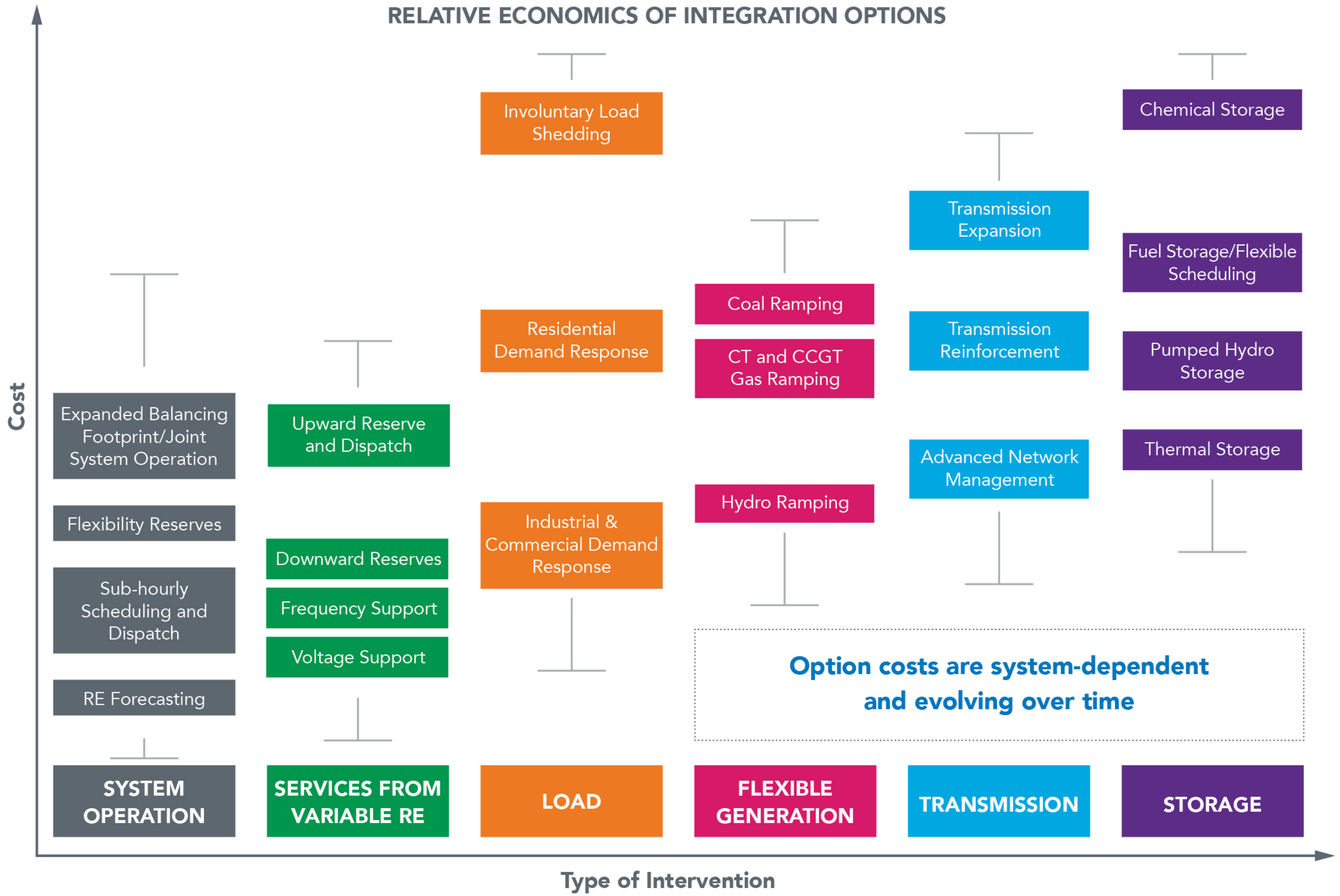


Source: Hummon et al. (2014). NREL/TP-7A40-60991

Balancing the System Takes Place at Multiple Timescales



Different Sources of Flexibility Help to Address Variability and Uncertainty



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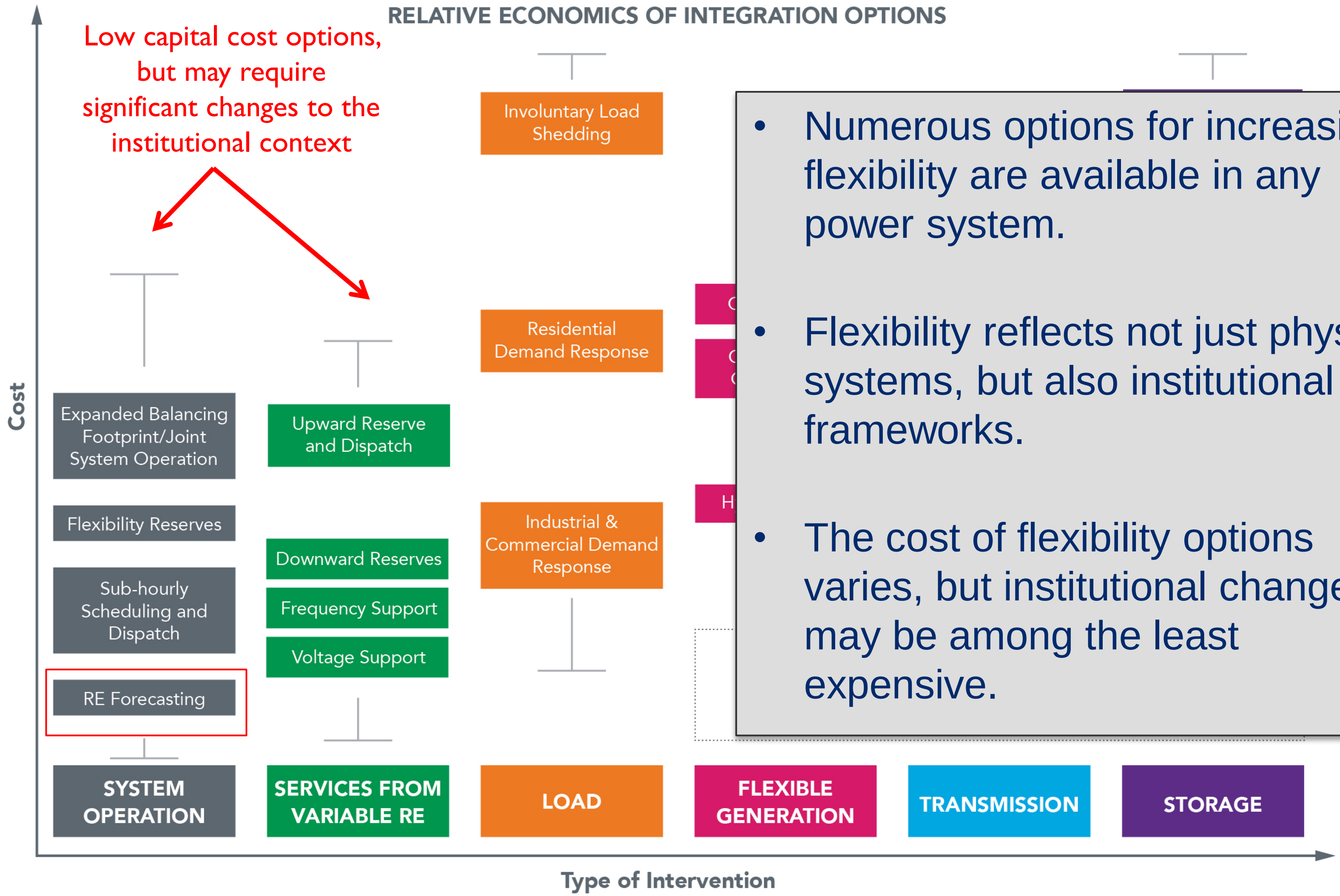


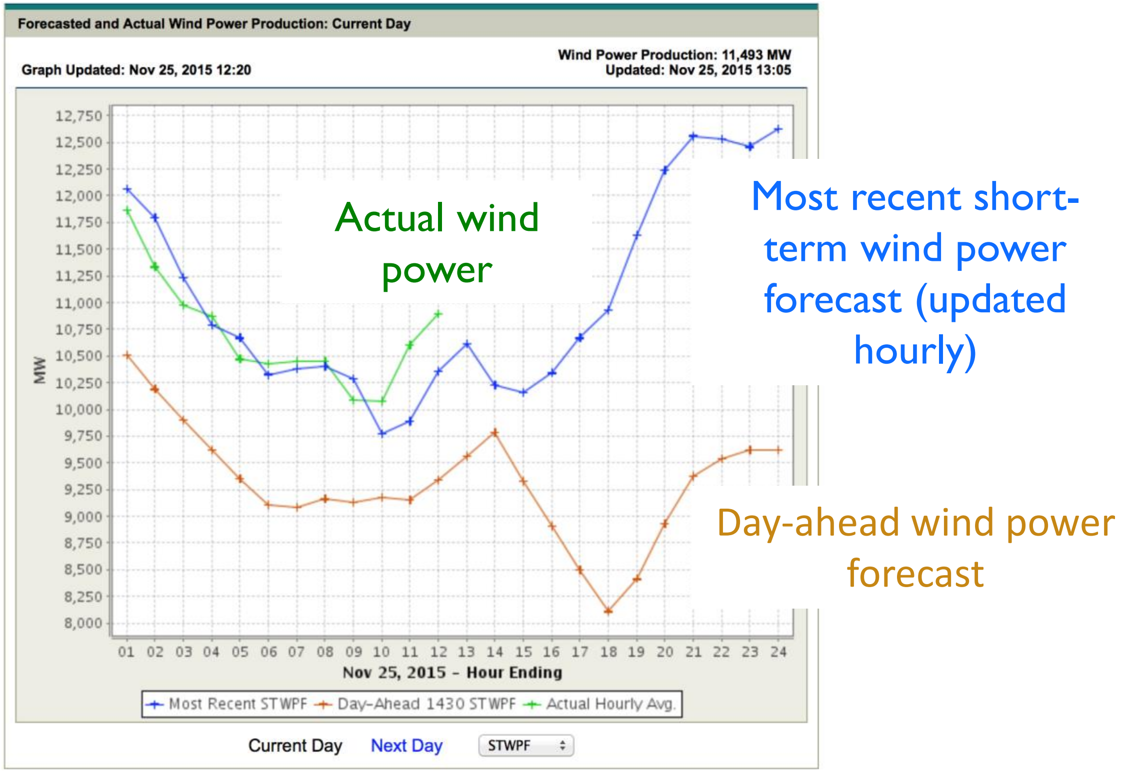
- Numerous options for increasing flexibility are available in any power system.
- Flexibility reflects not just physical systems, but also institutional frameworks.
- The cost of flexibility options varies, but institutional changes may be among the least expensive.

IMPACT OF WIND AND SOLAR FORECASTING ON POWER SYSTEM OPERATIONS

What is Forecasting?

In this webinar, we use the term *forecasting* primarily to refer to the near-term (usually up to day-ahead) prediction of electricity generation from wind and solar power plants.

Example: Texas' wind power production forecasts



Source: Electricity Reliability Council of Texas short-term wind power forecast

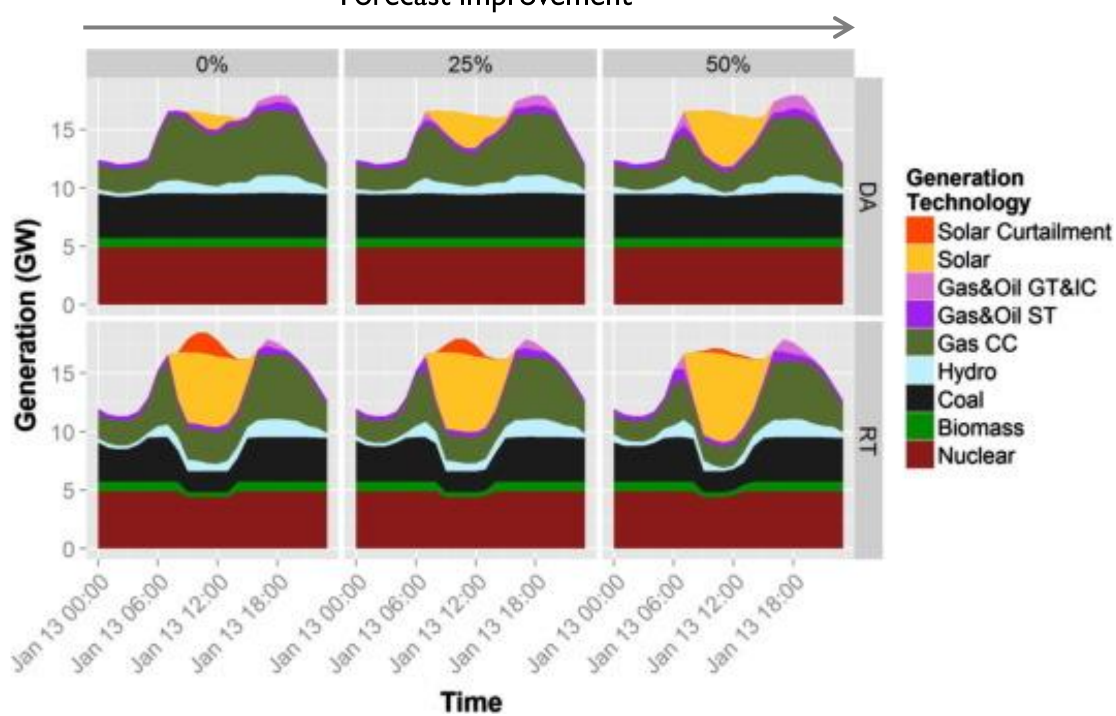
Load forecasting refers to the prediction of electricity demand.

Importance of Wind and Solar Forecasting

- High penetrations of variable RE increase the variability and uncertainty associated with power system operation

- Integrating wind and solar forecasts into scheduling and dispatch operations reduces uncertainty, helping to **lower costs and improve reliability**

Example: Solar power under-forecast

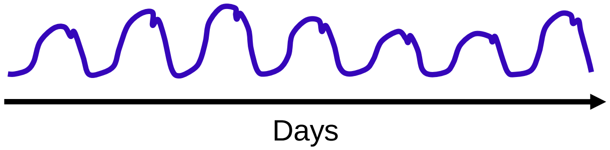


Each figure shows the dispatch stack for one day for the Day-ahead forecast (top row) and Real-time markets (bottom row)

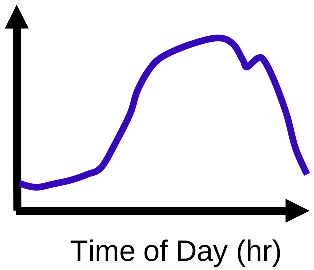
Source: Brancucci Martinez-Anido et al. (2016). *Solar Energy* 129.

How Do System Operators Use Forecasts? Part 1

- Long-term forecasts (1 week+)
  - Estimates of “typical” generation used for resource and O&M planning



- Day-ahead unit commitment
  - Day-ahead forecast, along with uncertainty band, is fed into scheduling and market decisions

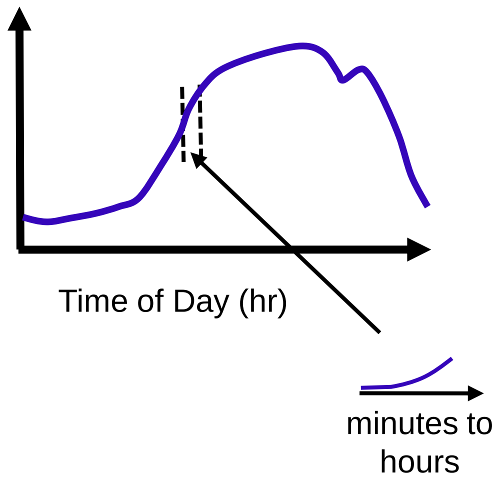


- Intra-day adjustments
  - Meteorologist flags changes to real-time traders
  - Reconfigure peaking plant schedules

Adapted from Justin Sharp

How Do System Operators Use Forecasts? Part 2

- Hour-ahead scheduling and trading
  - Meteorologist provides high/low uncertainty band
  - Use revised forecasts to optimize resources, markets, transmission; trading with neighbors

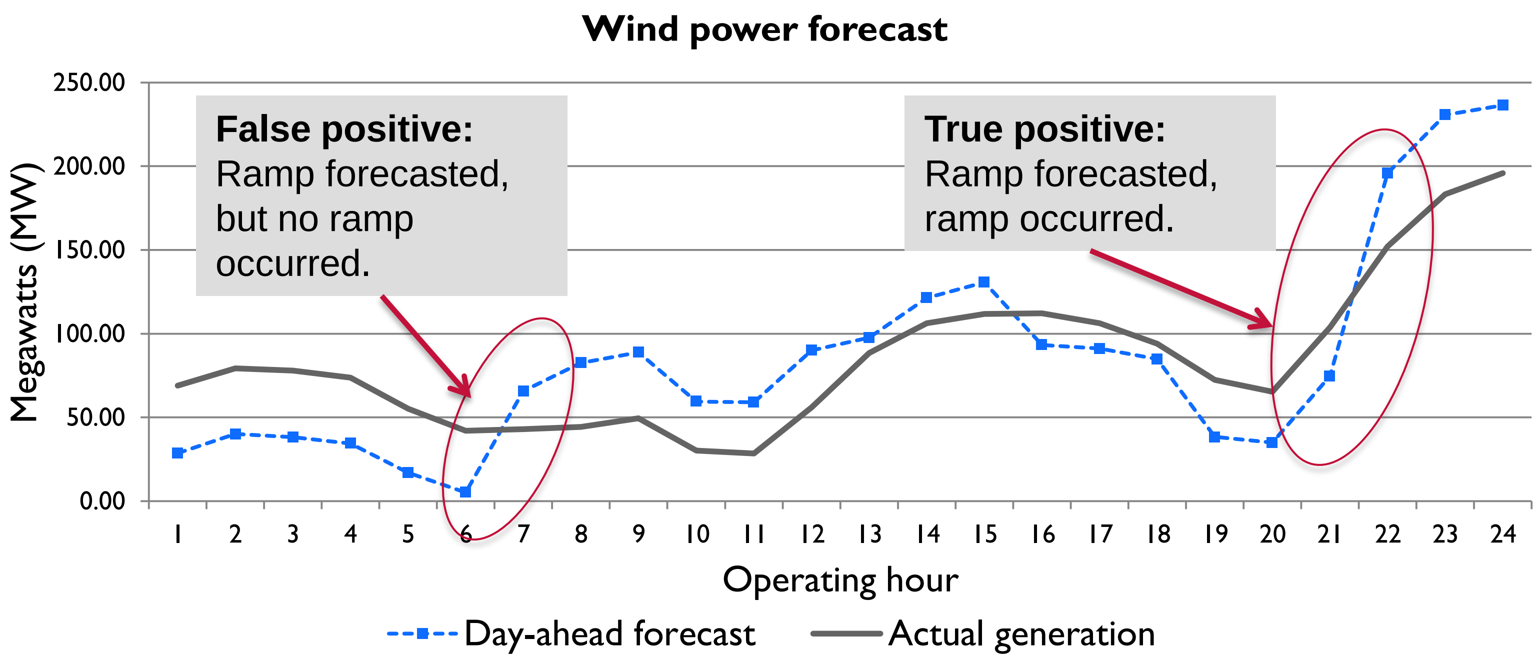


- Intra-hour dispatch
  - Value of forecast shifts to control room
  - Operators move other generators up/down in response to fluctuations
  - Assess reserves
    - Are reserves sufficient to last until next dispatch interval?
    - Can we handle ramps?
    - Are peaking resources needed?

Adapted from Justin Sharp

How Do System Operators Use Forecasts? Part 2

- A renewable energy **ramp** is a significant, sustained change in output due to changing resource conditions (i.e., wind speed, solar irradiance).
- There is no standard definition of what constitutes a ramp in renewable energy output, and ramps that are important in one system may be trivial in another.

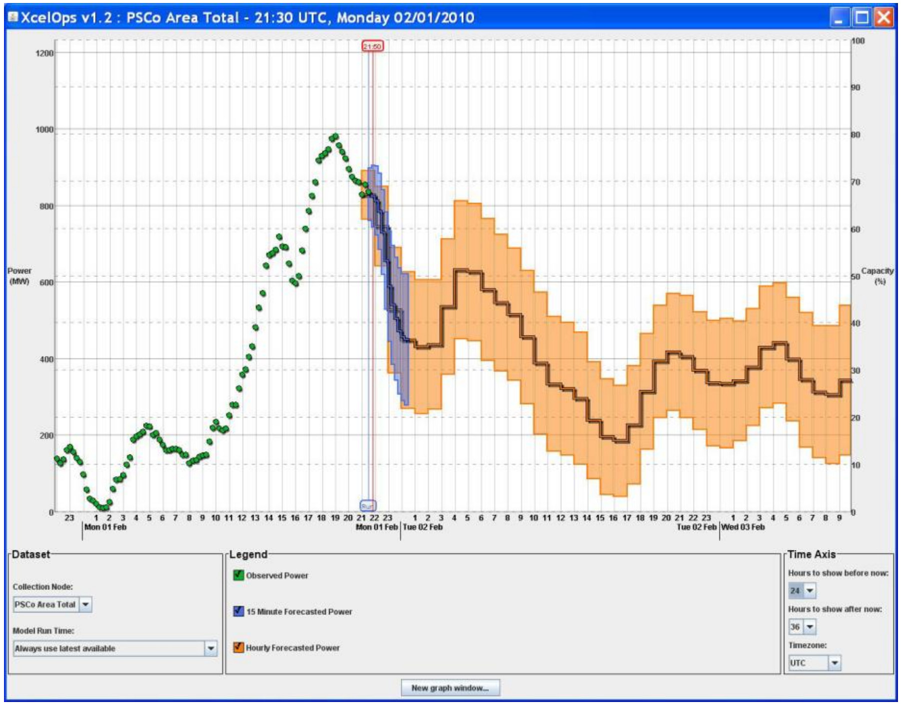


Forecasting Leads to Economic and Operational Benefits

- Improved unit commitment and dispatch efficiency
  - Utilization of least expensive units
  - Less “mileage” on operating units
  - Less starting of gas turbines and other fast acting units
- Reduced reserve levels
  - Regulation reserve
  - Flexible/load following reserve
- Decreased curtailment of RE generation

The Value of Forecasting: Xcel Energy Case Study

- Leading utility wind provider in the United States, and top 10 for solar.
  - 15% of total energy supply from wind in 2014
  - Up to roughly 70% instantaneous wind penetration
  - 5,794 MW wind capacity installed



- Partnered with two national laboratories to develop a state-of-the art forecasting model, which is maintained by a third party

Outcomes:

- Reduced average forecast error from 16.8% in 2009 to 10.10% in 2014
- Saved ratepayers US $49.0 million over the 2010-2014 period

Sources: Staton 2015; NCAR 2015; Xcel Energy 2015

Factors that Influence Forecasting Benefits

Physical Drivers

- The variability of the VRE resource
- Network size
- Generation resource mix
- Penetration level of wind and/or solar

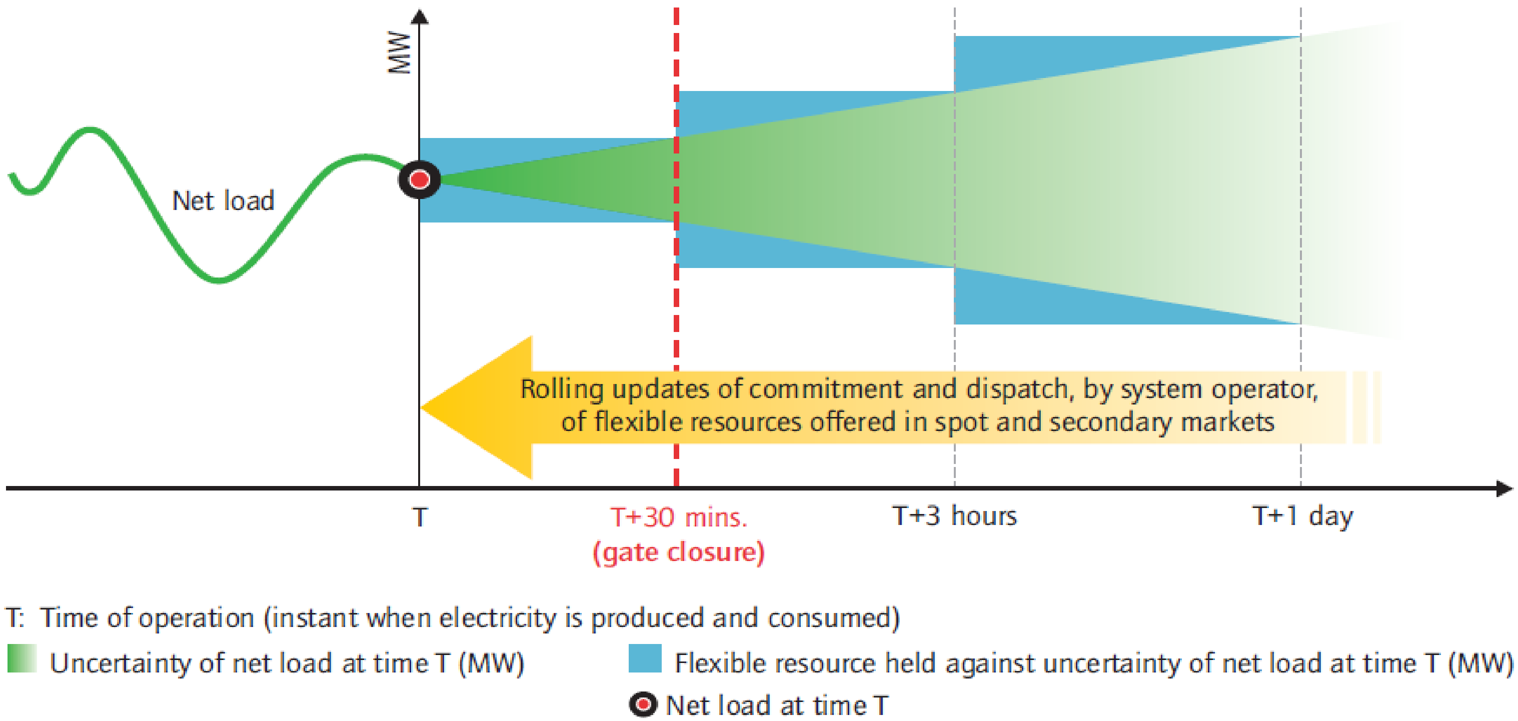
Institutional Drivers

- System operational practices, market design (e.g., scheduling, dispatch)
- Regulations and incentives/penalties
- Forecast timescale, accuracy, and reliability
- Operator confidence in the forecast
- How the forecast is used

Forecasting is not a silver bullet! It must be integrated with other flexibility solutions that favor VRE integration.

Adapted from Justin Sharp

More Frequent Decisions Reduce Uncertainty



While more frequent forecasts provide greater accuracy, they are only useful to the system operator up to the timeframe in which actions can be taken in response to the forecast.

Source: *Harnessing Variable Renewables – A Guide to the Balancing Challenge*, International Energy Agency, 2011

How are Forecasts Used in System Operations? Examples from North America

Balancing Authority	Type of variable RE forecasted	Forward Unit Commitment (Day-ahead, week-ahead, etc.)	Intra-day Unit Commitment	Transmission Congestion Management	Reserves	Management of Hydro or Gas Storage	Generation/ Transmission Outage Planning
Alberta Electric System Operator	Wind		X		X		
Arizona Public Service	Wind	X	X			X	
Bonneville Power Administration (BPA)	Wind			X	X	X	
California Independent System Operator (CAISO)	Wind and solar		X				
Glacier Wind	Wind				X		X
Idaho Power	Wind	X	X		X	X	
Northwestern Energy	Wind	X	X		X		
Sacramento Municipal Utility District*	Solar		X				
Southern California Edison*	Wind* and solar		X	X		X**	
Turlock***	Wind						
Xcel Energy	Wind and solar	X	X	X	X	X	

* *Also participants in the CAISO's Participating Intermittent Resource Program*

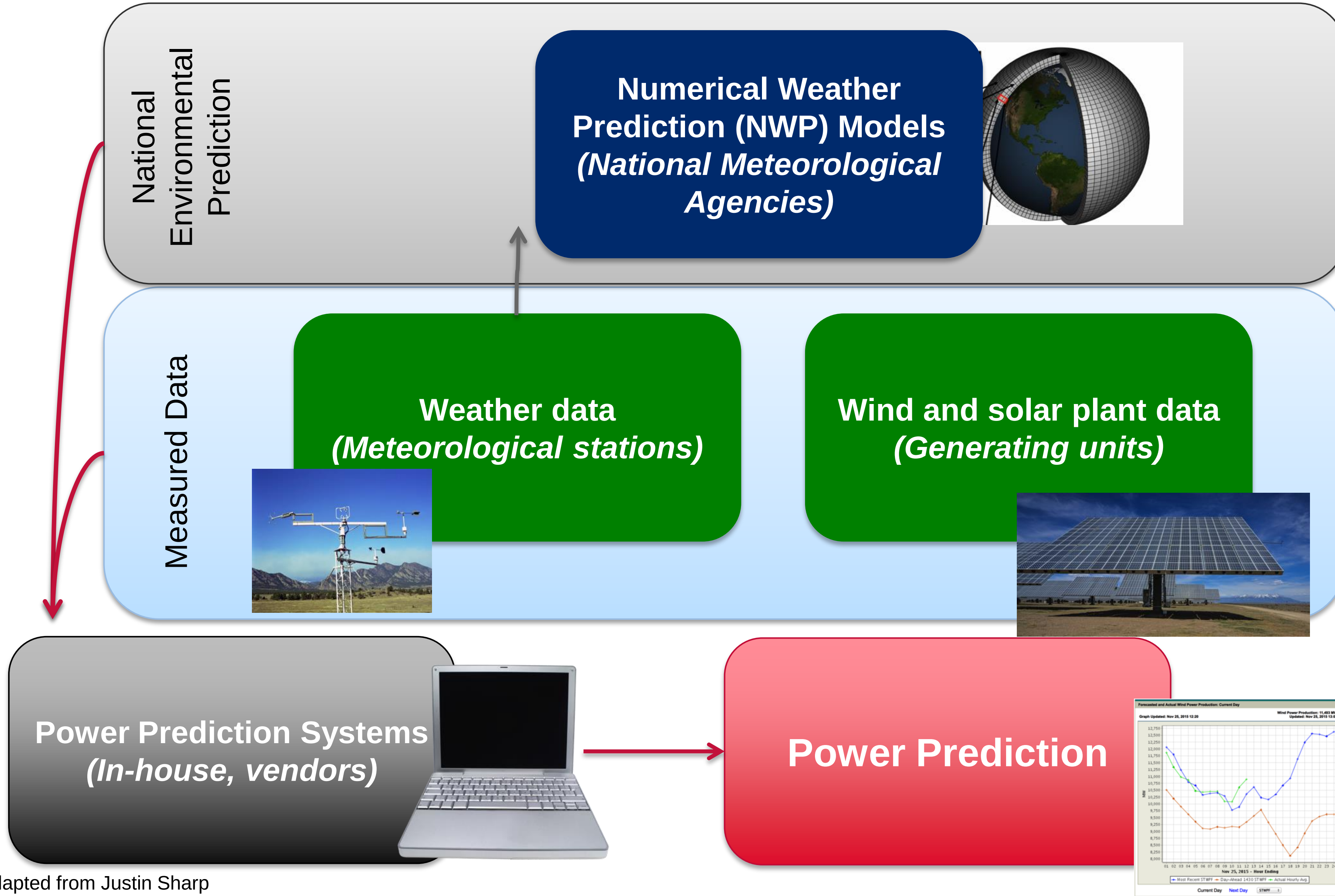
** *For hydro only, not natural gas*

*** *Uses forecast for trading, optimization, marketing, and compliance with BPA scheduling directives*

Source: Porter and Rogers, 2012. *Survey of Variable Generation Forecasting in the West.*

HOW ARE FORECASTS PRODUCED?

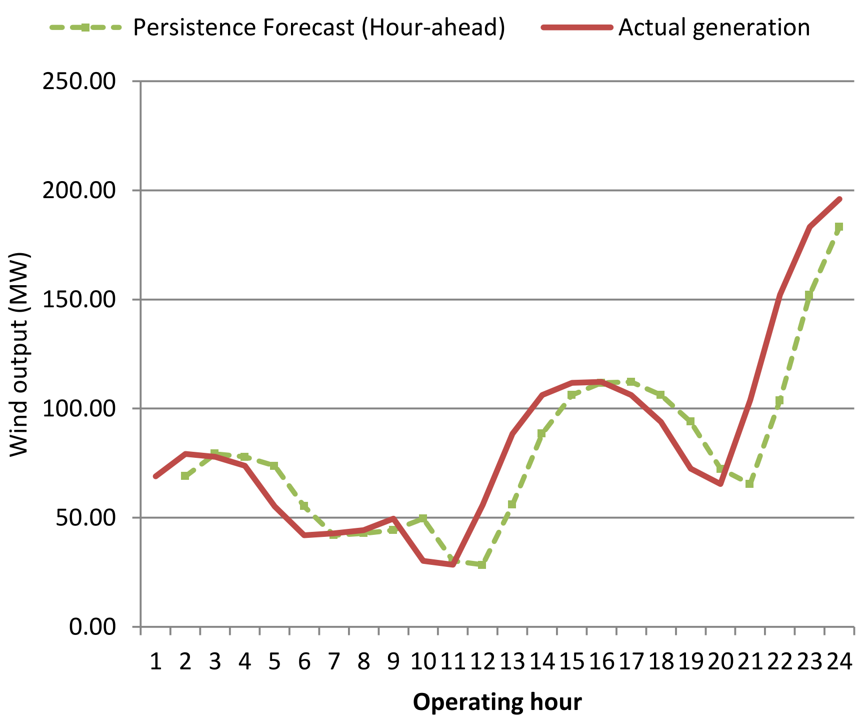
How are Wind and Solar Forecasts Produced?



Adapted from Justin Sharp

Forecasting Methods

- Physical (dynamical) methods
  - Inputs weather data (temperature, pressure, surface roughness, obstacles) into numerical weather prediction (NWP) models to create terrain-specific weather conditions
- Statistical methods
  - Uses historic and real-time generation data to statistically correct results derived from NWP models.
  - ***Persistence forecasting***: uses the last observation as the next forecast.



- Ensemble forecasting
  - Aggregates results from multiple different forecasts

Producing Forecasts: Timescales, Methods

	Type of Forecast	Time Horizon	Methods
Generation	Intra-hour	5-60 min	Statistical, persistence
	Short term	1-6 hours ahead	Blend of statistical and NWP models
	Medium term	Day(s) ahead	NWP with corrections for systematic biases
	Long term	Week(s), Seasonal, 1 year or more ahead	Climatological forecasts, NWP
Decision support	Ramp forecasting	Continuous	NWP and statistical
	Load forecasting	Day ahead, hour-ahead, intra-hour.	Statistical

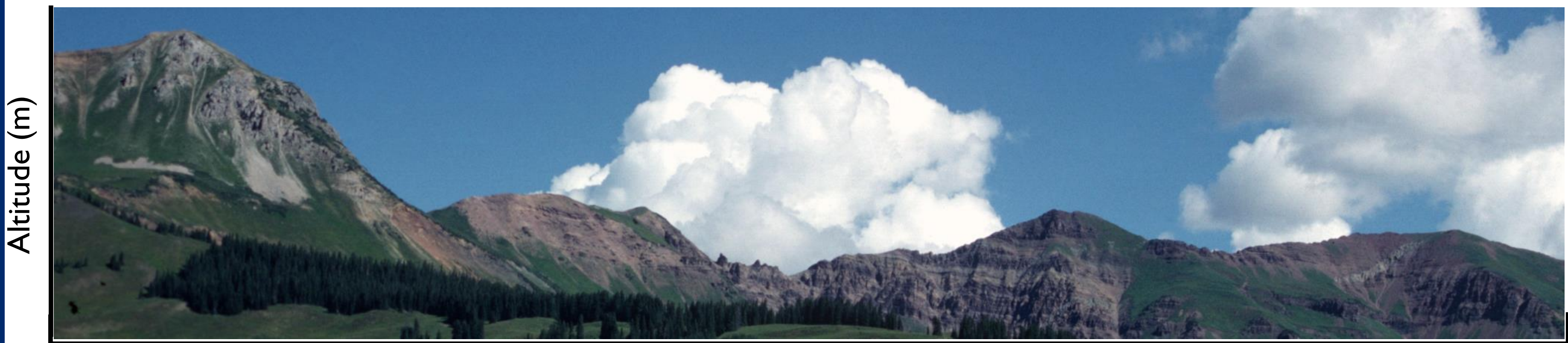
What Impacts Forecast Quality?

Examples:

- Meteorological data – e.g., density and frequency of observations
- NWP models – e.g., data assimilation, parameterization
  - Resolution—e.g., ability to represent terrain features that impact RE resource
- Operational information for wind and solar generators – e.g., turbine or panel availability, curtailment
- Power conversion algorithms

Example: Impact of Terrain and Spatial Resolution of Model

Terrain can have a significant impact on wind speed and direction



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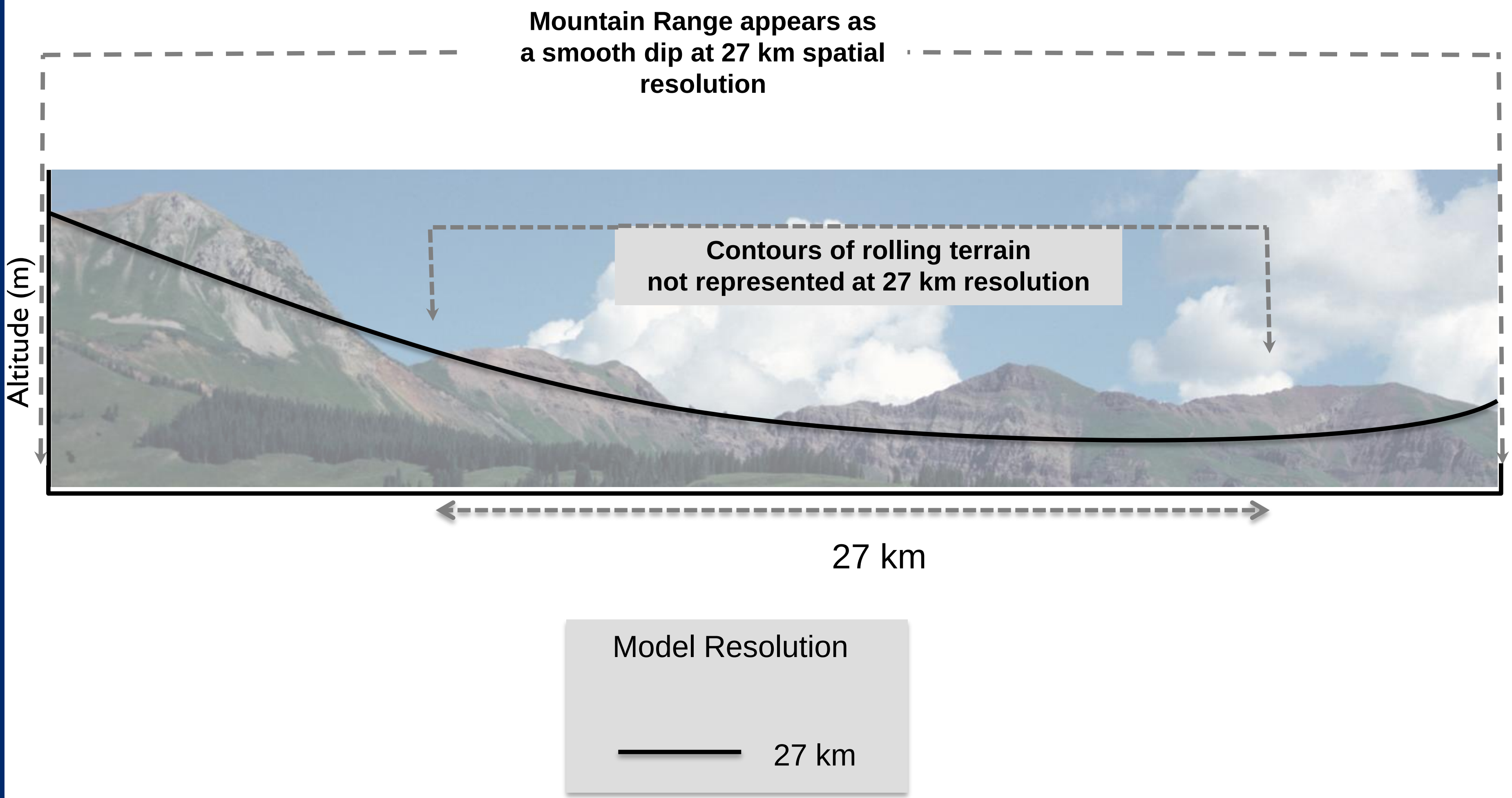

Illustrative example adapted from Justin Sharp, Sharply Focused

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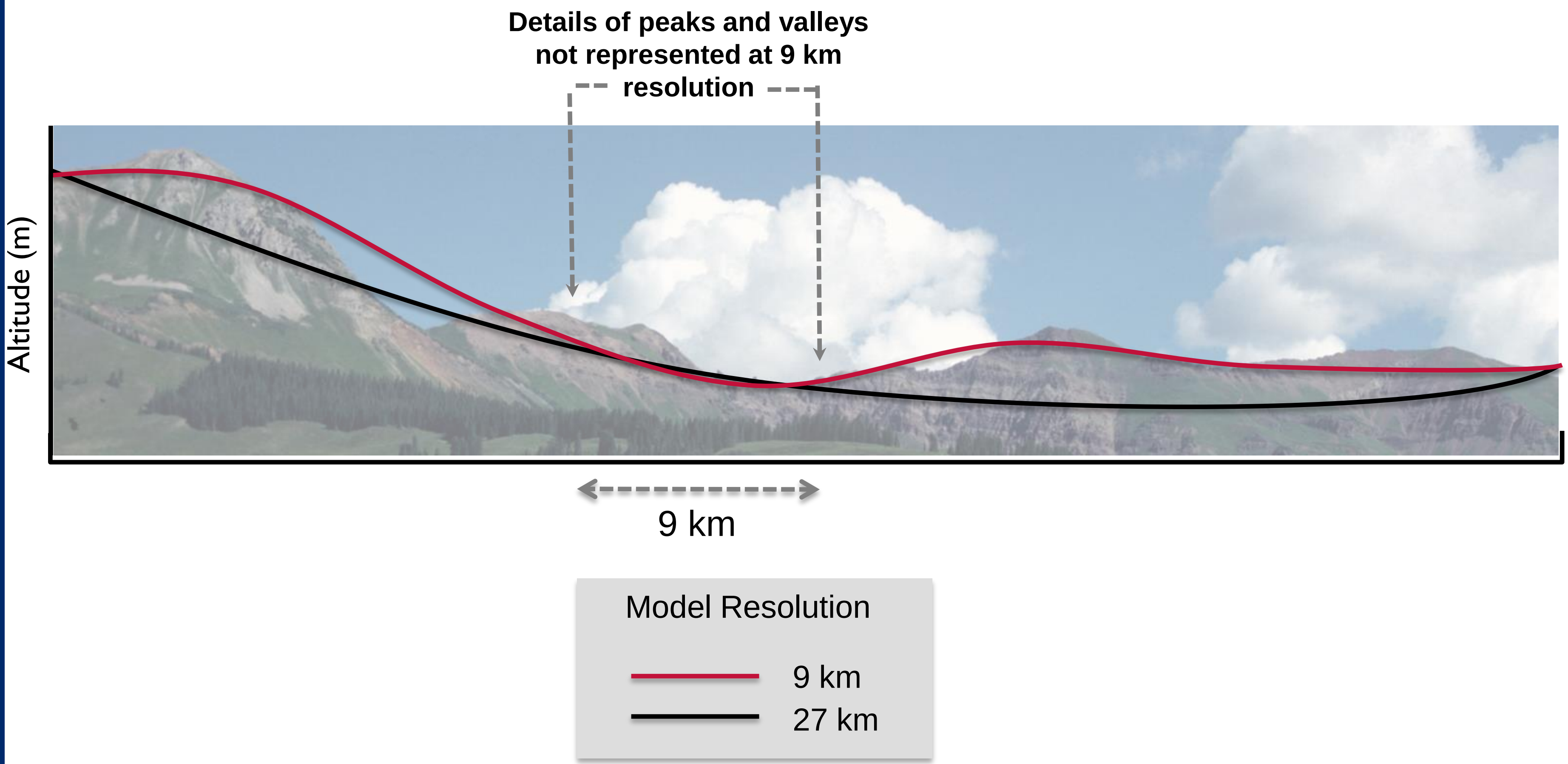

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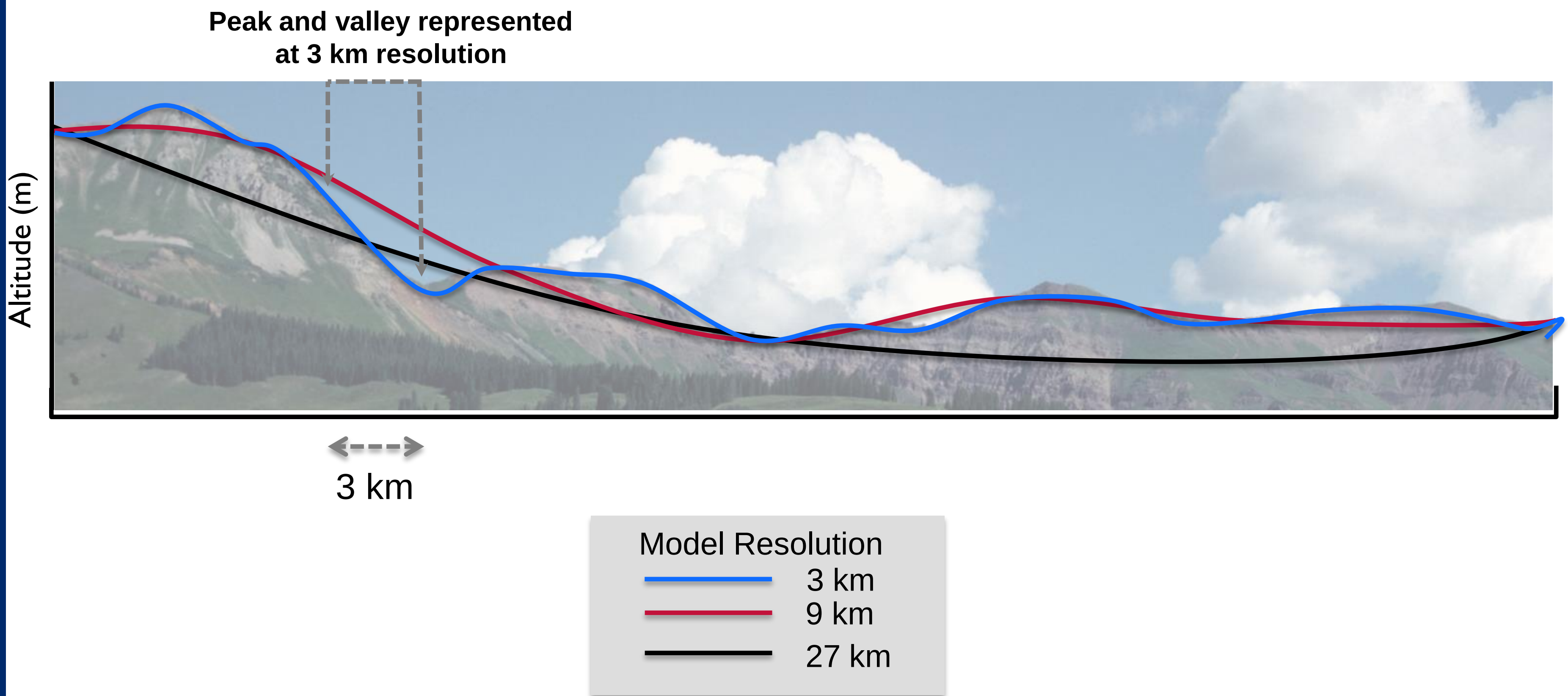

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CONSIDERATIONS FOR IMPLEMENTING FORECASTING SYSTEMS

Different Roles for Centralized vs. Decentralized Forecasts

Centralized Forecasting (by the system operator)

- Enables the use of forecasting in unit commitment and dispatch
- Requires mechanisms to obtain data from generators and encourage data quality
- Allows greater consistency and reduces uncertainty at the system level

Decentralized Forecasting (by the generator)

- Used by off-takers when making offers
- Helps project operators optimize operation and maintenance
- Informs operators of potential transmission congestion
- Limited scope can decrease utility

Centralized forecasting by the system operator, supported by generator-level forecasts from the plant operator, is widely considered a best practice approach.

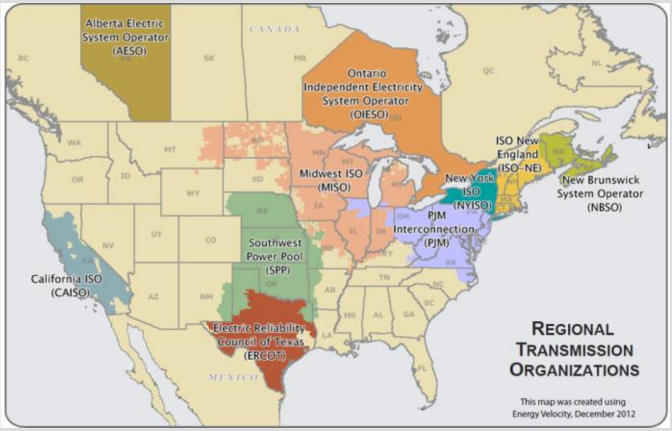
Who Accrues the Benefits of Improved Forecasting (and Bears the Risks of Poor Forecasting)?

Utilities

Variable Generation Plant Owners

Consumers

Independent System Operators (ISOs)



Those who bear the risks (financial, reliability) have the strongest interest in improving wind and solar forecasting

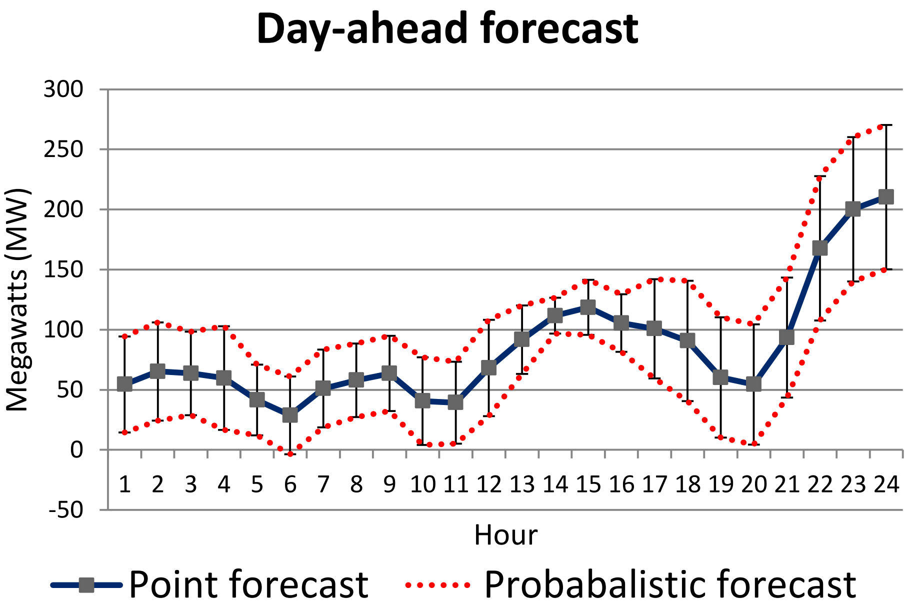
Understanding How Forecasts Can Impact Decisions

- Who will use forecasts, and how will they use them?
  - Market operations/scheduling
  - Transmission and distribution system operations?

- What time intervals and horizons are needed?
  - Hourly, 15 minute, day ahead, day of, hour ahead, etc.

- Point estimates (**deterministic forecasts**) can provide false sense of certainty

- Estimates of forecast uncertainty (**probabilistic methods**) can be extremely useful if the system has a good way of using the additional information



Monitoring and Verification is an Essential Component of Forecasting

Purposes of forecast verification:

1. **Monitor forecast quality** - how accurate are the forecasts and are they improving over time?
2. **Improve forecast quality** - the first step toward getting better is discovering what you're doing wrong.
3. **Compare the quality of different forecast systems** and a baseline - to what extent does one forecast system give better forecasts than another, and in what ways is that system better?
4. **Financial verification** – ensuring that generator reporting matches actual conditions

Adapted from Justin Sharp

Common Forecast Metrics

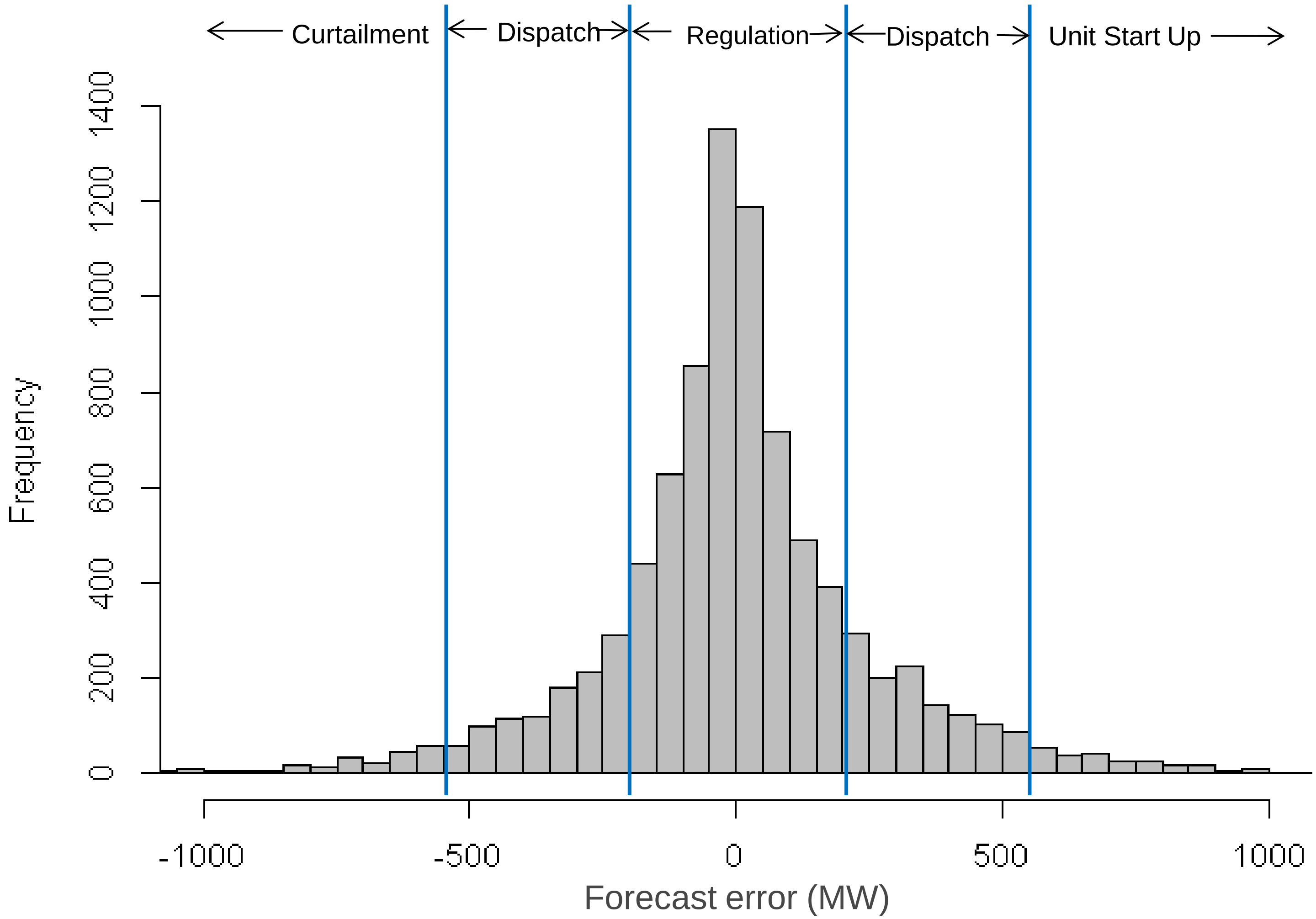
Forecast error is the difference between predicted and real-time generation from non-dispatchable VRE resources

- Mean bias error (MBE)
  - Indicates whether the model is systematically under- or over-forecasting
- Mean absolute error (MAE)
  - Measures the average accuracy of forecasts without considering error direction
- Root mean square error (RMSE)
  - Measures the average accuracy of forecasts without considering error direction and gives a relatively high weight to large errors

All metrics are wrong, but some are useful

Error rates are not static; they vary based on time of year, extent of spatial or geographic aggregation, among many other factors

Where are Improvements Needed?

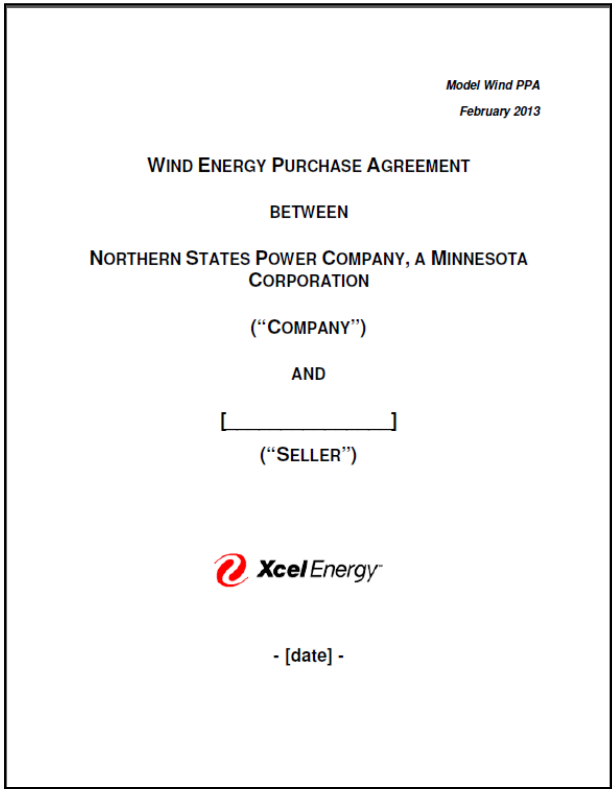


The system was designed to accommodate small amounts of uncertainty. Large forecast errors are the most costly.

Data Collection Strategies for System Operators

- Policy mandates
  - May be implemented for utility-scale and distributed generation
  - [FERC Order 764]
- Interconnection or market requirements set by federal and state government, utilities, and RTO/ISO
- Power purchase agreements
- Penalties/rewards
- Partnerships with meteorological agencies
- Third-party vendors

Xcel Energy's Model PPA includes provisions for forecasting data collection



Model Wind PPA
February 2013

WIND ENERGY PURCHASE AGREEMENT

BETWEEN

NORTHERN STATES POWER COMPANY, A MINNESOTA CORPORATION

("COMPANY")

AND

[______________]

("SELLER")

Xcel Energy

- [date] -

http://www.xcelenergy.com/staticfiles/xe/Corporate/Corporate%20PDFs/Model_Power_Purchase_Agreement.pdf

What Data is Needed to Set up a Forecasting System?

Static

- Plant location (Latitude, Longitude)
- Installed Capacity
- Historic Data (training data)

Dynamic

- Real-Time Generation
- Availability Data
- Park Potential (potential total output based on available resources at the wind/solar farm level)
- Meteorological Data

Options for Procuring Forecasts

- Third-Party Vendors
  - Vendor uses proprietary power prediction models to estimate generation.
  - Requires wind and solar plant data from generators or the system operator.
  - In-house meteorologists still play a role in reviewing forecasts and identifying critical periods.
  - Typical forecasts are selling for USD $200/project/month to $2000/project/month (source: Justin Sharp)
- In-house Forecasting
  - Staff meteorologists/analysts develop power prediction models and are responsible for assembling and validating meteorological and plant data.
  - Can allow flexibility for custom and state-of-the-art approaches that reflect system-specific concerns.
  - Will be significantly more expensive to develop and require significantly more computing power and expertise to maintain than vendor forecasts.

Working with vendors can be an inexpensive, introductory way to get experience with forecasting. This can be a valuable first step.

ACTIONS TO SUPPORT FORECASTING SYSTEMS

Example Areas for Early Actions

- Update interconnection standards, power purchase agreements to enable data gathering

- Work with national meteorological institutes to improve underlying weather data or access to it

- Facilitate training of operators on meteorology, how to interpret forecasts, and work with vendors

- Support vendor trials and development of a smooth IT interface between forecast vendors and users

Key Takeaways

- Forecasting facilitates the integration of variable renewable energy to the grid by reducing uncertainty and improving the efficiency of operations at multiple timescales.

- Better information is only valuable when it leads to better decisions
  - Understanding areas where forecasting improves decision-making is a first step in considering how to implement forecasting systems
  - Interpreting forecasts is a critical element of effective implementation

- Centralized and decentralized have unique value; in general, moving toward centralized forecasting is most effective in reducing uncertainty at the system level.

- There is no one-size-fits-all approach to collecting data and procuring and monitoring forecasts. Power systems should tailor their forecasting programs to their unique context and needs.

QUESTIONS AND DISCUSSION

Contacts and Additional Information

Webinar Panel

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Learn more at greeningthegrid.org