



USAID
FROM THE AMERICAN PEOPLE



Transforming the Global Power Sector

Open Tools and Data for Renewable Energy Integration

June 2023

Welcome!

Welcome to our webinar! Here are a few notes about using Zoom:

- This webinar is **being recorded** and will be shared with attendees.
- You will be **automatically muted** upon joining and throughout the webinar.
- Please use the **Q&A function** to ask questions to be addressed during the Q&A portions. You can find this function in your toolbar.
- Please use the **chat feature** to add comments and share input.
- If you have **technical issues**, please use the chat feature to message **Isabel McCan** or **Holly Darrow**.
- You can adjust your audio through the **audio settings**. If you are having issues, you can also dial-in and listen by phone, which can be found in your registration confirmation email.

To view today's code-package for side-by-side learning, visit:
<https://globalpst.org/transforming-the-global-power-sector-open-data-and-tools-for-renewable-energy-integration/>

Webinar Overview

Presenters



Karin Wadsack
Program Manager
*National Renewable
Energy Laboratory
(NREL)*



Galen Maclairin
Senior Energy
Researcher
*National Renewable
Energy Laboratory
(NREL)*



Kate Doubleday
Researcher
*National Renewable
Energy Laboratory
(NREL)*

Agenda – Day 1

- 1 Welcome and Housekeeping**

- 2 Opening Remarks**

- 3 Renewable Energy (RE) Data Explorer: High Quality Data for Decisions**

- 4 Enabling Power Sector Transformation at Scale**

- 5 Introduction to Production Cost Modeling (PCM)**

- 6 Open-Source Tools for PCM Development**

- 7 Overview of Sample Analysis and Training Materials**

Agenda – Day 2

- 1 Recap of Day 1
- 2 Overview of PCM Workflow and Sample Analysis
- 3 Resource Visualization and Site Screening in RE Data Explorer
- 4 PCM Demonstration in Sienna\Ops
- 5 Open-Source Training Resources
- 6 Audience Q&A
- 7 Wrap Up

Opening Remarks

Karin Wadsack

National Renewable Energy Laboratory

Global Power System Transformation (G-PST) Consortium

What?

A global consortium focused on support to power system operators with advanced, low-emission solutions

Who?

Founding System Operators (FSOs)



*Core Team
Technical Institutes*

*Developing Country
System Operators*

*Indonesia, Ukraine, Vietnam, Thailand, India,
South Africa, Pakistan, Morocco, Peru,
Colombia, Panama, and others*

Why?

To drive the development and transfer of the **technical and engineering knowledge** necessary for power system operators at the **speed and scale** required to support the global energy transition

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Advancing Action in Five Key Areas

1. System Operator Research & Peer Learning



Perform cutting edge applied research to create novel system operator solutions and globally disseminate and infuse new insights through peer learning

2. System Operator Technical Assistance



Provide implementation support to scale established best practice engineering and operational solutions

3. Foundational Workforce Development



Build the inclusive and diverse workforce of tomorrow through enhanced university curriculum and technical upskilling for utility and system operator staff

4. Localized Technology Adoption Support



Adapt modern power system technologies to individual country contexts through testing programs and standards development activities

5. Open Data and Tools



Support rigorous planning, operational analysis and enhanced real-time system monitoring through open data and tools

CORE TEAM – All Core Team members contribute to all activity pillars



REGIONAL LEADS – Coordinate regional peer learning networks and country-level technical assistance delivery efforts for Africa, Asia, and Latin America and the Caribbean



INTERIM SECRETARIAT – Work program coordination, partnerships and support, outreach, etc.



The USAID-NREL Partnership

www.nrel.gov/usaid-partnership

The U.S. Agency for International Development (USAID) and NREL partner with developing countries to decarbonize and transform energy systems around the world by addressing critical aspects of deploying advanced energy systems.

USAID-NREL PARTNERSHIP STRATEGIC PILLARS

Provision of demand-driven technical assistance through USAID Mission engagements, global knowledge platforms, and project implementation



ADVANCED & FRONTIER POWER SYSTEMS

Utility-scale clean energy generation, transmission, distribution



INNOVATION & GRID INTERACTION IN BUILDINGS

Energy efficiency, distributed generation, storage



ELECTRIC MOBILITY & SUSTAINABLE TRANSPORT

Electric vehicles, charging infrastructure, hydrogen



INTEGRATED ENERGY SOLUTIONS

Holistic energy sector scenario planning, impact assessments, and programming



JUST ENERGY TRANSITIONS

Gender equity, air quality, resilience, job creation, energy access – foundational to all USAID-NREL activities



BEST-IN-CLASS ENERGY DATA & ANALYTICS

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USAID-NREL Global Knowledge Platforms

The USAID-NREL Partnership's global knowledge platforms provide free, state-of-the-art knowledge products, tools, and support on common and critical challenges to scaling up power, buildings, transport and integrated energy solutions



www.re-explorer.org



www.i-jedi.org



www.greeningthegrid.org



www.resilient-energy.org

Spotlight on Grid Integration Resources



- High-quality renewable energy data for decisions
- Integrated geospatial visualization
- Free data downloads



- Grid integration toolkit
- Best practice frameworks, case studies, and technical resources
- Variable Renewable Energy (VRE) Guidebook for Practitioners



Public Data and Open-Source Tools: Transforming Energy



Catalyzing innovation



Accelerating deployment



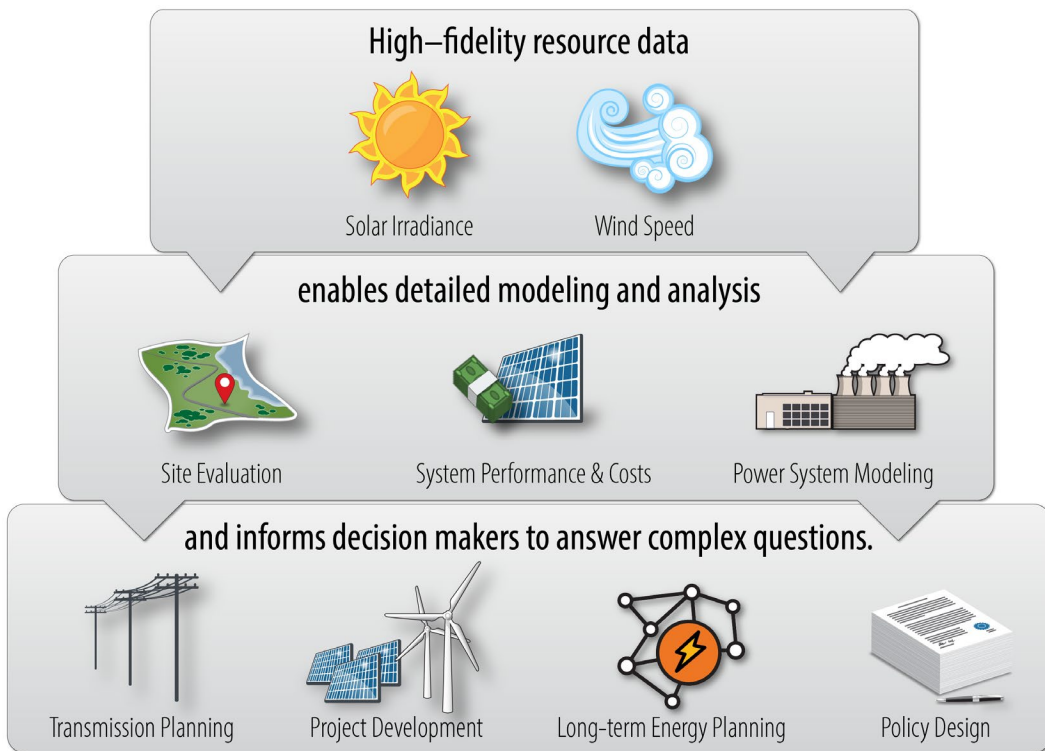
Empowering decision-makers

High Quality Data for Renewable Energy Decision-Making

Galen Maclaurin

*National Renewable Energy
Laboratory*

High-Quality Data Accelerates Energy Transitions



Motivation and Objectives

DEMOCRATIZING DATA: Growing need for free timeseries wind and solar resource data across the globe to support:

- Project feasibility assessments
- Regional and national target setting
- Detailed power systems modeling
- Assessment of PV-Wind complementarity

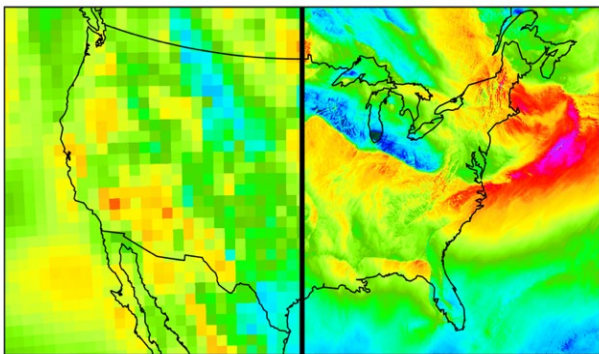
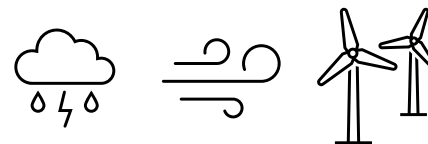


Figure Credit: Ryan King, NREL

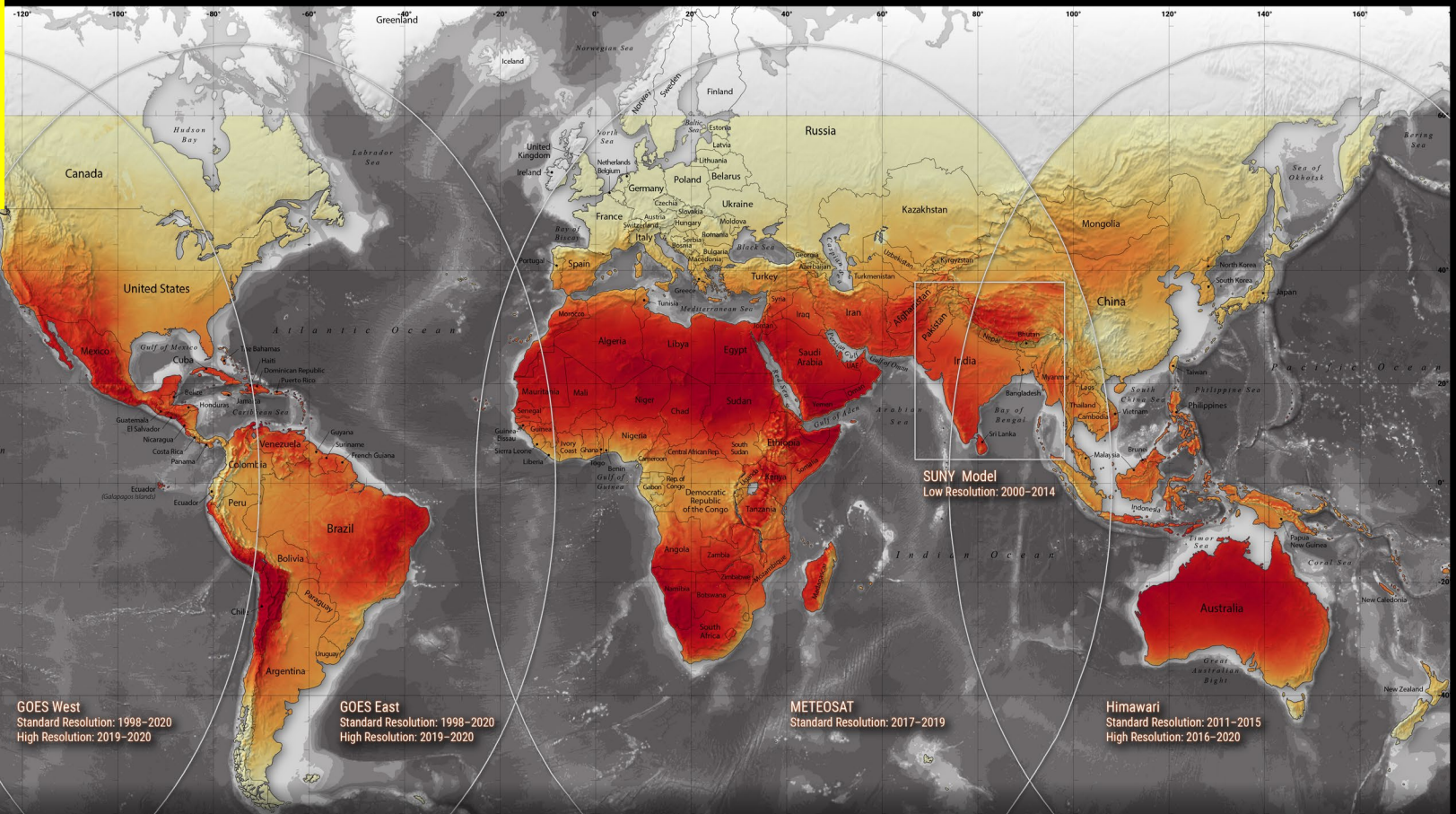
OBJECTIVES: Provide high-quality, publicly available wind and solar resource data



VALUE PROPOSITION: Capture important atmospheric processes for the wind energy community:

- High-accuracy, meso-scale wind flow
- Sub-hourly to interannual resource variability
- Accurate vertical wind profile (wind shear)
- Ramping rates at fine temporal scales

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GOES West
Standard Resolution: 1998–2020
High Resolution: 2019–2020

GOES East
Standard Resolution: 1998–2020
High Resolution: 2019–2020

METEOSAT
Standard Resolution: 2017–2019

SUNY Model
Low Resolution: 2000–2014

Himawari
Standard Resolution: 2011–2015
High Resolution: 2016–2020

Low Resolution: 10 km spatial at hourly intervals
Standard Resolution: 4 km spatial at 30-minute intervals
High Resolution: 2 km spatial at 10-minute intervals

GLOBAL SOLAR IRRADIANCE DATA SETS
HIGH RESOLUTION SOLAR IRRADIANCE AND ATMOSPHERIC DATA

www.re-explorer.org



Data available at 5-minute intervals across the contiguous United States.
For more information, visit: nsrdb.nrel.gov

Solar Data Development Algorithm

NREL's Physical Solar Model (PSM)

- Characterizes absorption and scattering of solar radiation from clouds and aerosols
- Models the transfer of solar radiation through Earth's atmosphere
- Considers interactions with atmospheric constituents (e.g., CO₂, O₃, H₂O) and land surface
- Visit <https://nsrdb.nrel.gov/> for more information.

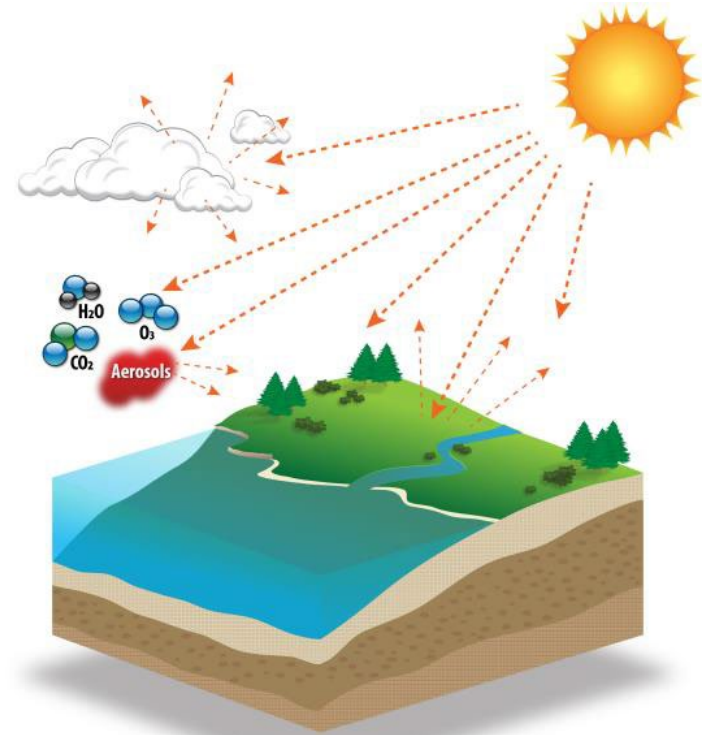
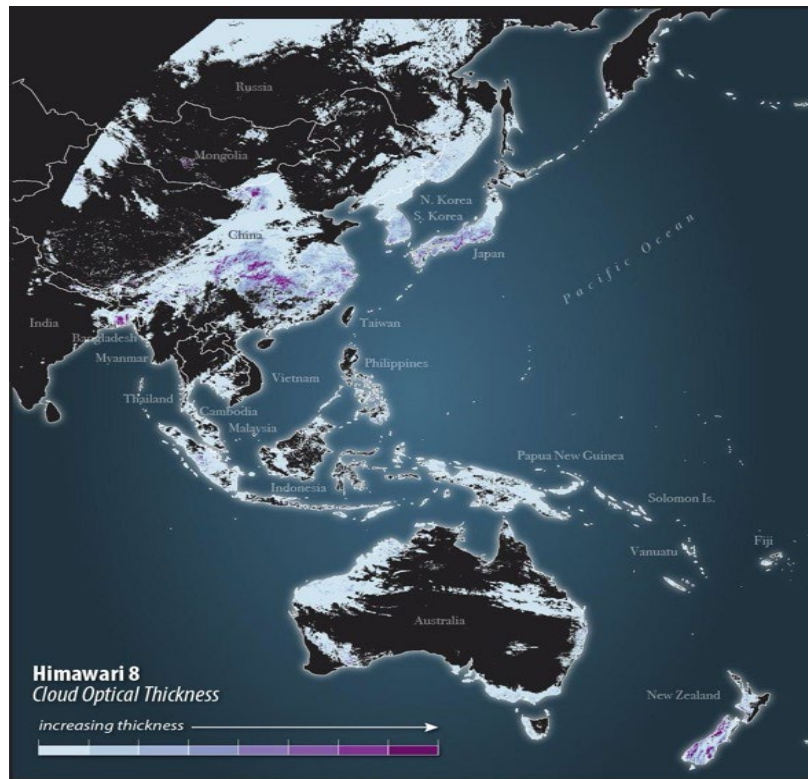


Illustration by Billy Roberts, NREL

Himawari Satellite Imagery

- Cloud characteristics are a key to estimate absorption and scattering of the incoming solar radiation
- Imagery from the Japanese Meteorological Agency's (JMA's) Himawari 7 and 8 satellites
- NREL partnered with the University of Wisconsin to model cloud type, optical thickness, and properties.

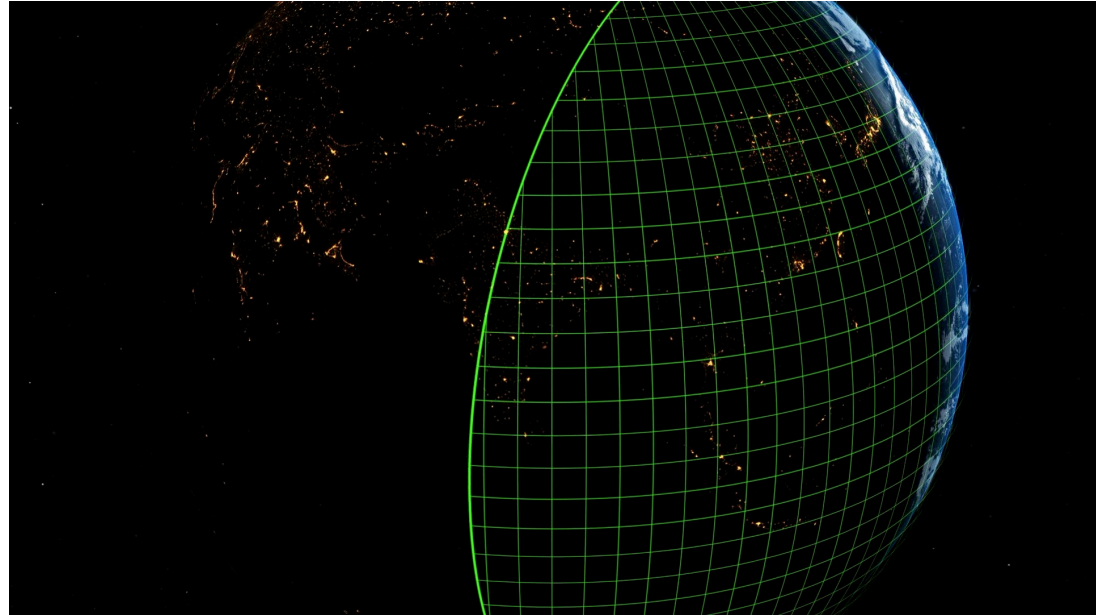


Cloud optical thickness shown for April 1, 2019. Illustration by Billy Roberts, NREL

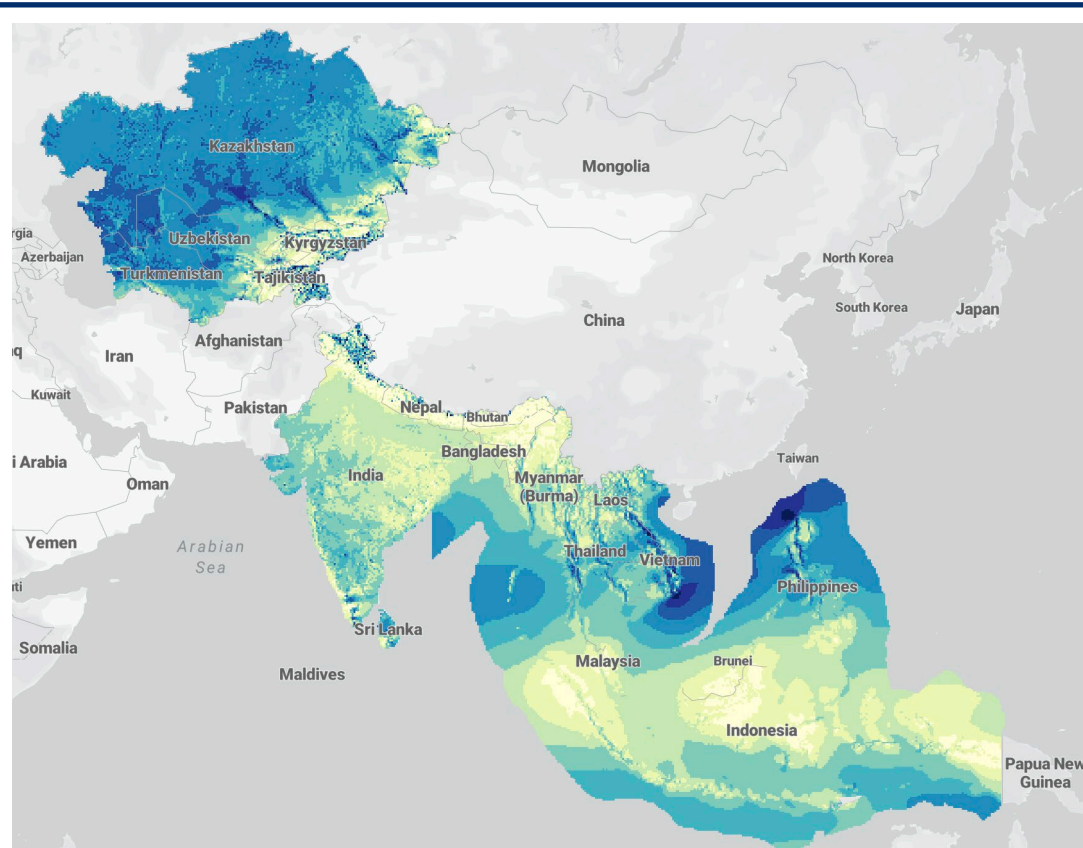
Southeast Asia Solar Resource Data

Released in February 2021:

- High fidelity solar radiation data covering SE Asia and much of the Indo-Pacific region.
- 10-years of high spatial and temporal resolution data and a Typical Meteorological Year (TMY) data set.
- Easily accessible, free, and open data.



NREL Wind Resource Data



NREL Wind Data - Asia

- Central Asia – 2015
 - 2km, 15 minute - Kazakhstan
 - 9km, 15 minute - other countries
- South Asia – 2017
 - 3km, 5 minute
 - India, Sri Lanka, Nepal, Bhutan
- Southeast Asia 2007-2021
 - 3km, 15 minute
 - Association of Southeast Asian Nation (ASEAN) countries and Bangladesh

A New Paradigm for Wind Resource Assessment

Combine cutting edge techniques in numerical weather prediction and machine learning

Weather Research and Forecasting (**WRF**) Model



Generative Adversarial Networks (**GANs**)



Meso-Scale Wind Resource Timeseries Data

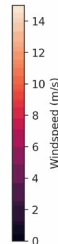
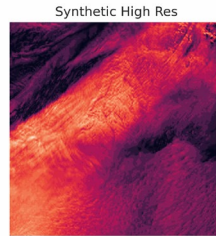
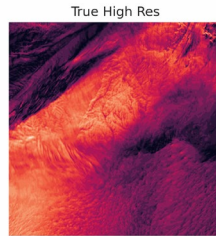
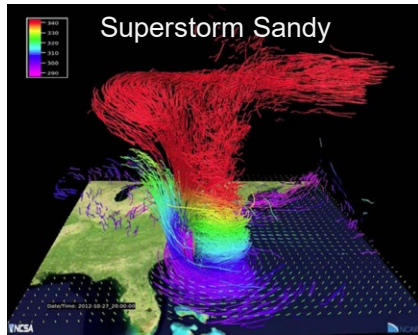


Figure Credit: Ryan King, NREL

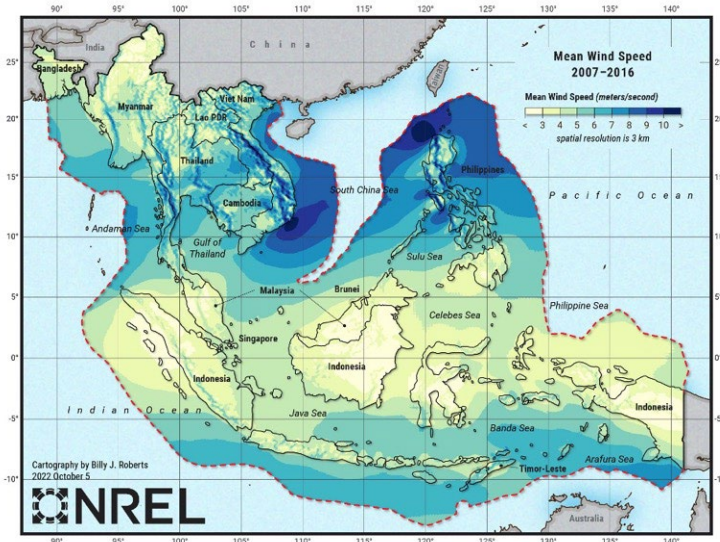


Figure Credit: Billy Roberts, NREL

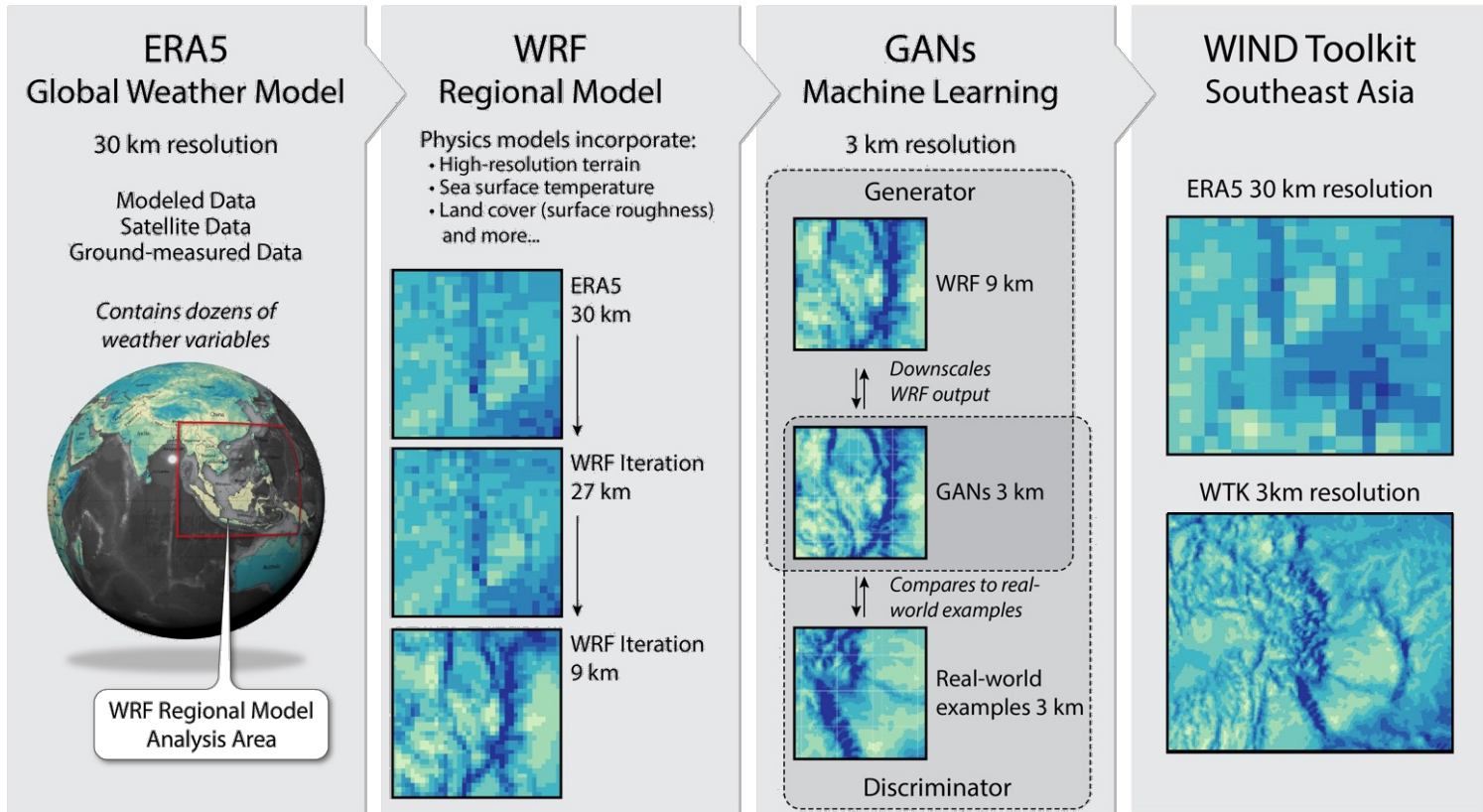
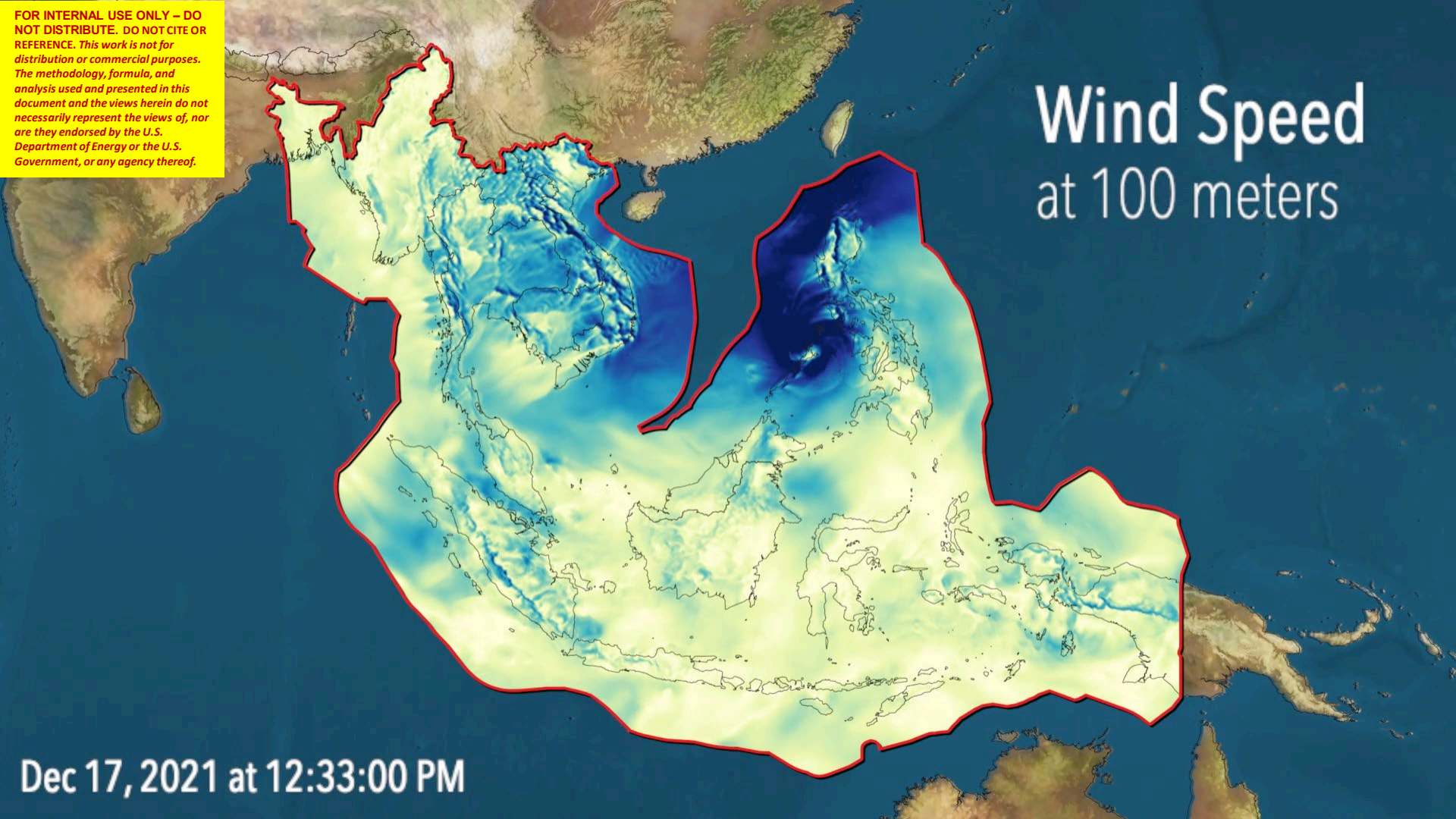


Figure Credit: Billy Robert, NREL

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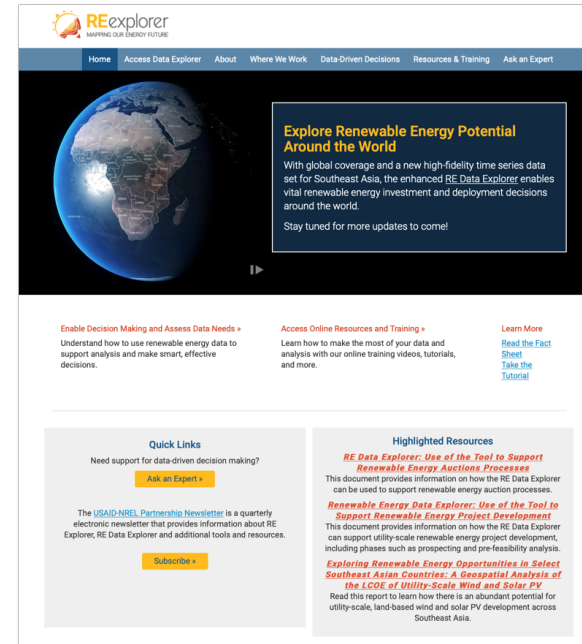
Wind Speed at 100 meters



Dec 17, 2021 at 12:33:00 PM

Renewable Energy (RE) Data Explorer

- A user-friendly geospatial visualization tool for analyzing renewable energy potential and informing decisions.
- Open data download repository for high-quality renewable energy resource data.
- Support for renewable energy decision-making.

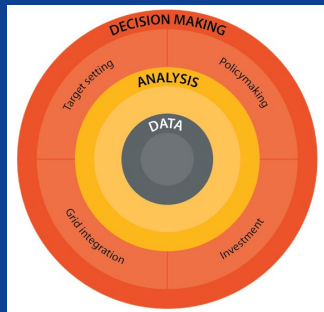


www.re-explorer.org

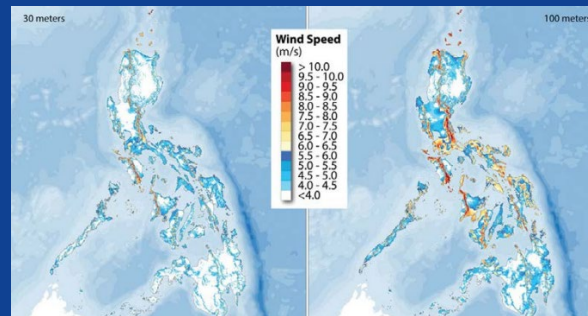
Additional Resources

[RE Data Explorer](#) was developed to support data-driven renewable energy analyses that can inform key renewable energy decisions globally.

Access the [RE Data Explorer Data-Driven Decisions webpage](#) to learn how renewable energy data can support informed renewable energy target setting, policy making, investment, and power sector planning



Leverage the [Renewable Energy Data, Analysis, and Decisions: A Guide for Practitioners](#) to enhance your capability to make informed and effective renewable energy decisions using high-quality renewable energy data.



Additional Resources

Learn more about renewable energy resource data developed for the Southeast Asia region.



Developing Southeast Asia Solar Resource Data to Support the Clean Energy Transition in the Region

Through the Advanced Energy Partnership for Asia, USAID and NREL have produced a data set covering 2018 through 2019 with 2km spatial and 10-minute temporal resolution.

Similar to other data sets produced with the PSA, this data set enables a wide range of research in photovoltaic (PV) energy and accompanying solar power (SPV) to assess system performance, estimate plant costs, and inform planning decisions. Furthermore, this high-fidelity resource data set can be used to support solar energy market expansion and inform siting, target setting, renewable energy auctions, and other high-fidelity decisions ranging from the impact of the track scale to accurate renewable energy deployment throughout Southeast Asia, as shown in Figure 4.

To address this need, with funding from USAID under the Advanced Energy Partnership for Asia, the U.S. Department of Energy National Renewable Energy Laboratory (NREL) developed and released high spatial (2-kilometer) and temporal (10-minute) resolution solar resource data for the entire Southeast Asia region available at <https://www.nrel.gov/data/psa/psa-solar>. This high-resolution data set was developed in collaboration with the University of Wisconsin and the National Oceanic and Atmospheric Administration. NREL developed the Physical Solar Model (PSM) dataset, which employs a physics-based approach to provide the radiative transfer of solar radiation through the atmosphere. The PSM uses an high-resolution cloud properties derived from imagery provided by the Japanese Meteorological Agency's Himawari weather satellite. The final data set was validated using ground measurements across Southeast Asia and Oceania and meets high levels of accuracy.


Analyses
Planning and investment
systems generation and cost analysis
technical potential
capacity expansion
production cost modeling

High-Fidelity Solar Data

Decisions
renewable energy target setting
investment and financing
solar siting prospecting
long-term energy planning
grid integration and system operation

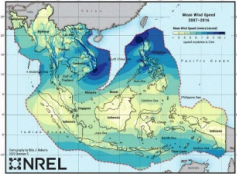
Figure 4. High-quality, reliable data set at the level of critical decisions enabling energy transitions. (Source: NREL/PSA, 2020)

[Developing Southeast Asia Solar Resource Data to Support the Clean Energy Transition in the Region](#)



High-Resolution Southeast Asia Wind Resource Data Set

High-fidelity, time series wind data for Southeast Asia is publicly available via RE Data Explorer



Informing Wind Decisions

Well-informed decision-making is a key part of integrating variable renewable energy into the global energy marketplace. Stakeholders and country leaders need trusted, publicly available, comprehensive data to meet their ambitious renewable energy targets and plan global power system decarbonization within reach. Successful decarbonization strategies will optimize the use of wind energy. As Southeast Asia seeks to establish its clean energy economy, access to accurate wind data will be essential in planning new and ongoing wind energy projects. Considering Southeast Asia's increasing population and development needs, demand for clean energy will only grow, necessitating accurate data for decision-making.

The U.S. Agency for International Development (USAID) and the National Renewable Energy Laboratory (NREL) are supporting Southeast Asian nations through the [Global Access Data Explorer](#) by providing a high-fidelity time-series wind resource data set to accelerate renewable energy integration and increase access to clean, affordable, and reliable energy throughout the region.

This data set, available through the USAID/NREL Partnership [Renewable Energy Data Explorer](#), provides access to fine spatial resolution wind data. This provides technical actions, project developers, researchers, and other stakeholders can use this data with modeling software to inform decisions regarding wind energy project development, long-term energy planning, and power system operations. **With a 3-km spatial and 15-minute temporal resolution and a 15-year record, this first-of-its-kind public data set supports the informed deployment of wind energy across Southeast Asia.**

Building on Prior Models

The fifth generation of the European analysis data set (ERA5) provided the initial atmospheric conditions across the globe needed to develop the wind resource data set. Using a combination of satellite data and ground measurements, ERA5 models global historical weather and climate conditions, including the atmospheric processes that impact wind resources. ERA5 has a spatial resolution of 30 km and a long-term record with hourly time steps. However, the local conditions that are important for wind energy production are not captured sufficiently at this spatial resolution.

The Weather Research and Forecasting (WRF) model was then used to refine the resolution of the ERA5 data set. WRF is a multidimensional model that predicts environmental variables (e.g., wind speed and direction, temperature) across space and time at multiple heights above the surface. It also models the lower atmosphere with higher

[High-Resolution Southeast Asia Wind Resource Data Set](#)

Enabling Power Sector Transformation at Scale

Variable Renewable Energy Grid Integration

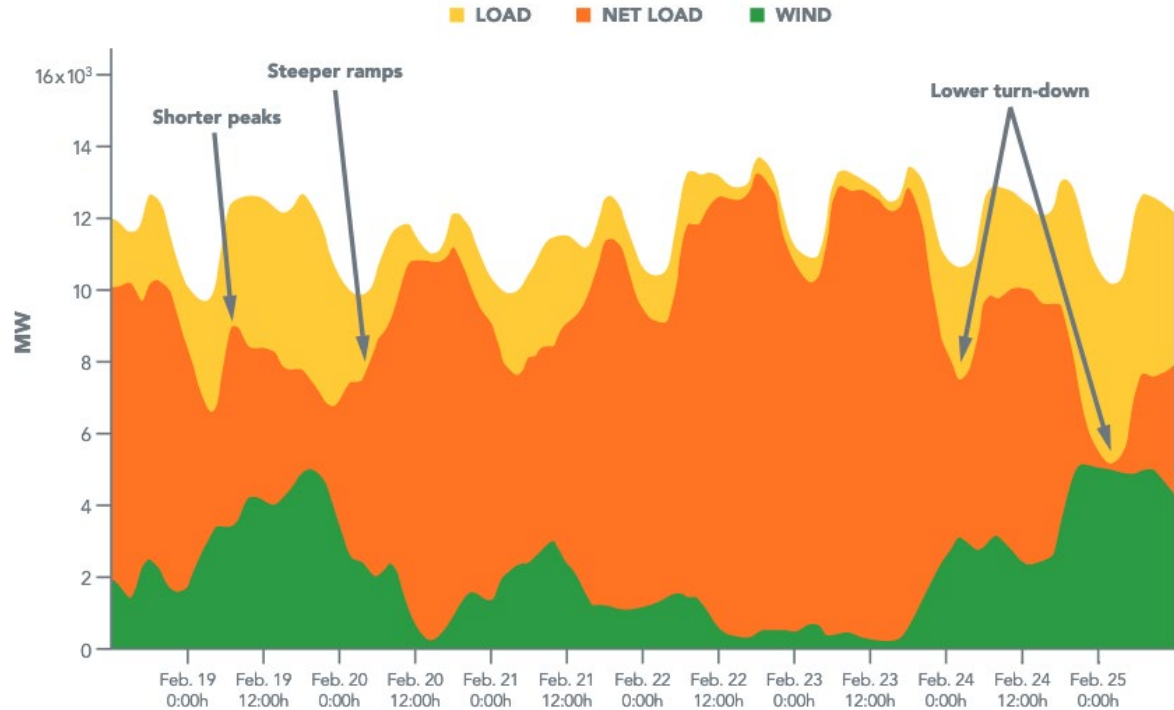
Kate Doubleday

National Renewable Energy Laboratory

VRE Challenges

Variable renewable energy (VRE) resource challenges:

- Variable and uncertain
- Not “dispatchable”
- Does not provide inertia (without synthetic inertia controls)



[Flexibility in 21st Century Power Systems](#)

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The background of the slide features two men in business attire standing in front of a wall. The wall is covered with various charts and maps. On the right, there is a large area chart with a y-axis labeled 'Fraction' ranging from 0.15 to 0.75 and an x-axis with years from 2006 to 2018. The chart shows several stacked areas in different colors (blue, green, yellow, orange, red, purple) representing different energy sources. A legend on the left side of the chart lists categories such as 'New Wind (GW)', 'Wind', 'Nuclear', 'Coal', 'Gas', 'Hydro', 'Geothermal', 'Solar PV', 'Solar Thermal', 'Biomass', 'Coal with CCS', and 'Other'. Below the chart, there is a map of the United States with the text 'WinDS R' visible. The title 'Walter's Premise' is overlaid on a dark horizontal band across the middle of the image.

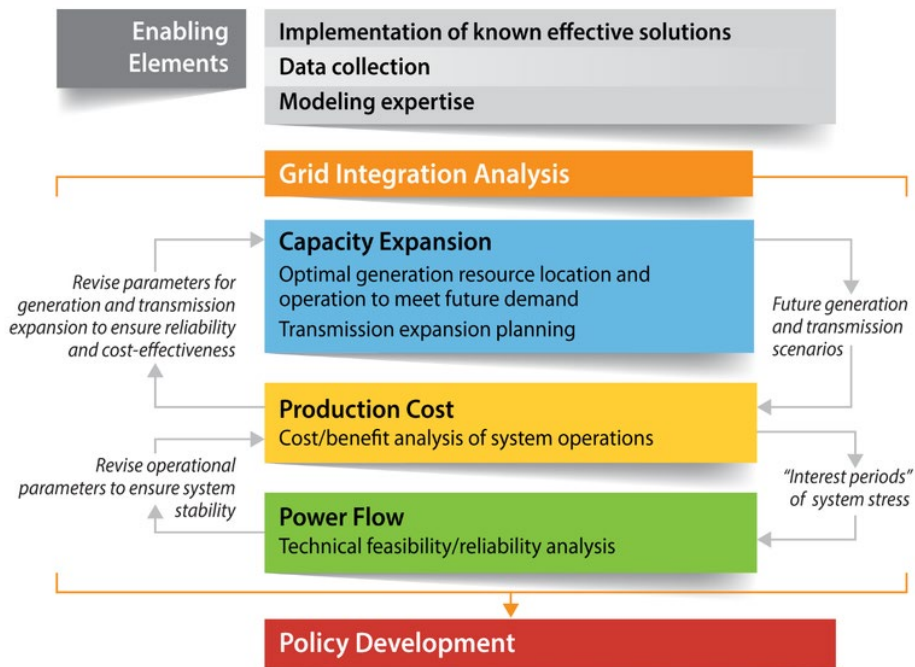
Walter's Premise

“The large scope and focus on today’s dominant conventional energy forms [in existing models] do not allow a detailed treatment of the more important issues for wind energy technologies.”

From: Short, W., N. Blair, D. Heimiller, and V. Singh (2003). Modeling the long-term market penetration of wind in the United States

What is grid integration?

Grid integration is the practice of power system planning, interconnection, and operation that enables efficient and cost-effective use of variable renewable energy (VRE) while maintaining the stability and reliability of the grid.



Types of grid integration analyses

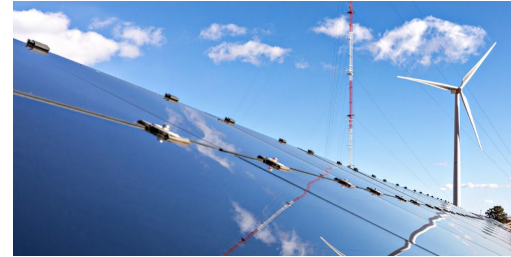
[Integrating Variable Renewable Energy Into the Grid: Key Issues](#)
[The Evolution of Power System Planning with High Levels of Variable Renewable Generation](#)

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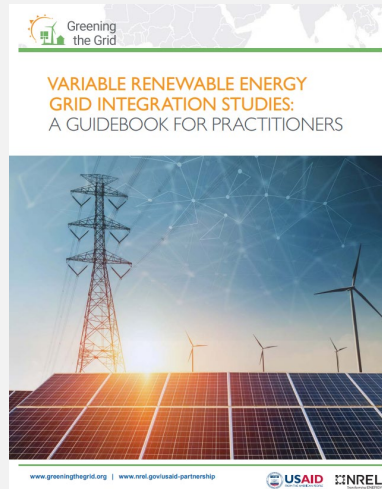
Greening the Grid: An Expert-Curated Toolkit for VRE Integration



Access the [Grid Integration Toolkit](#) on [Greening the Grid](#) to unlock an extensive collection of expertly assembled and annotated resources that can facilitate your understanding of the key topics for integrating variable renewable energy into the grid

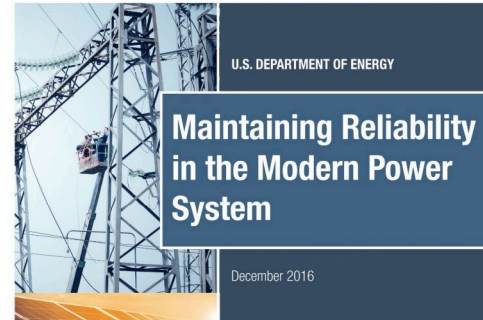


Grid Integration Toolkit



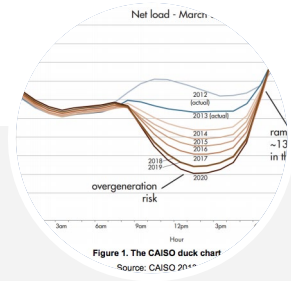
Check out the [Variable Renewable Energy Grid Integration Guidebook for Practitioners](#) to gain a comprehensive understanding of strategies and good practices for conducting a high-quality grid integration study

Four Pillars of Power System Reliability



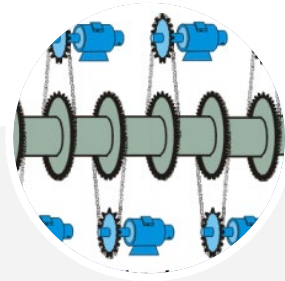
Capacity

Power generation and transmission capacity must be sufficient to meet peak demand for electricity.



Flexibility

Power systems must have adequate flexibility to address variability and uncertainty in demand (load) and generation resources.



Frequency

Power systems must be able to maintain steady frequency.

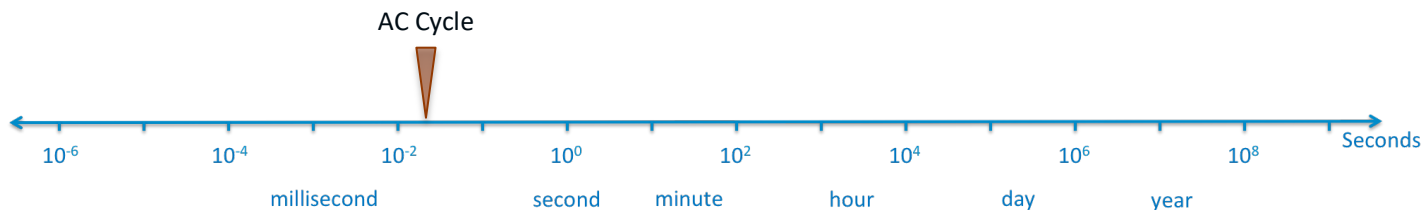


Voltage

Power systems must be able to maintain voltage within an acceptable range.

Relevant grid decision timescales

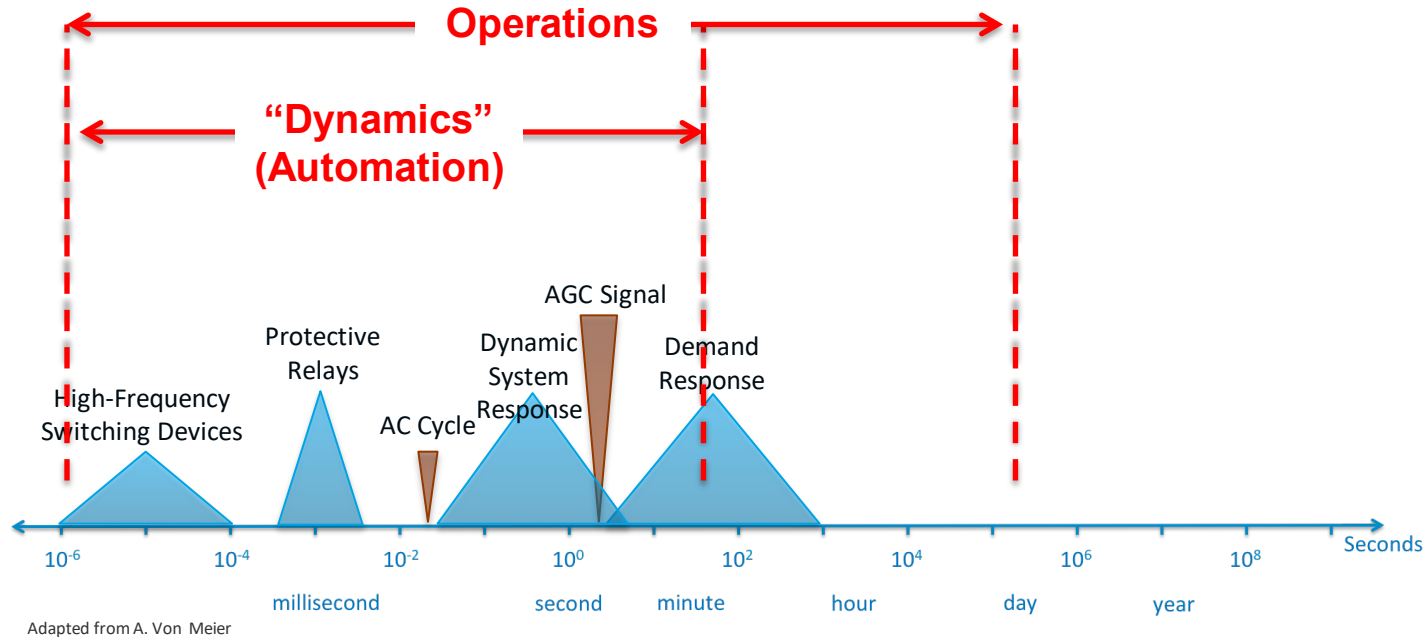
span 15 orders of magnitude



Adapted from A. Von Meier

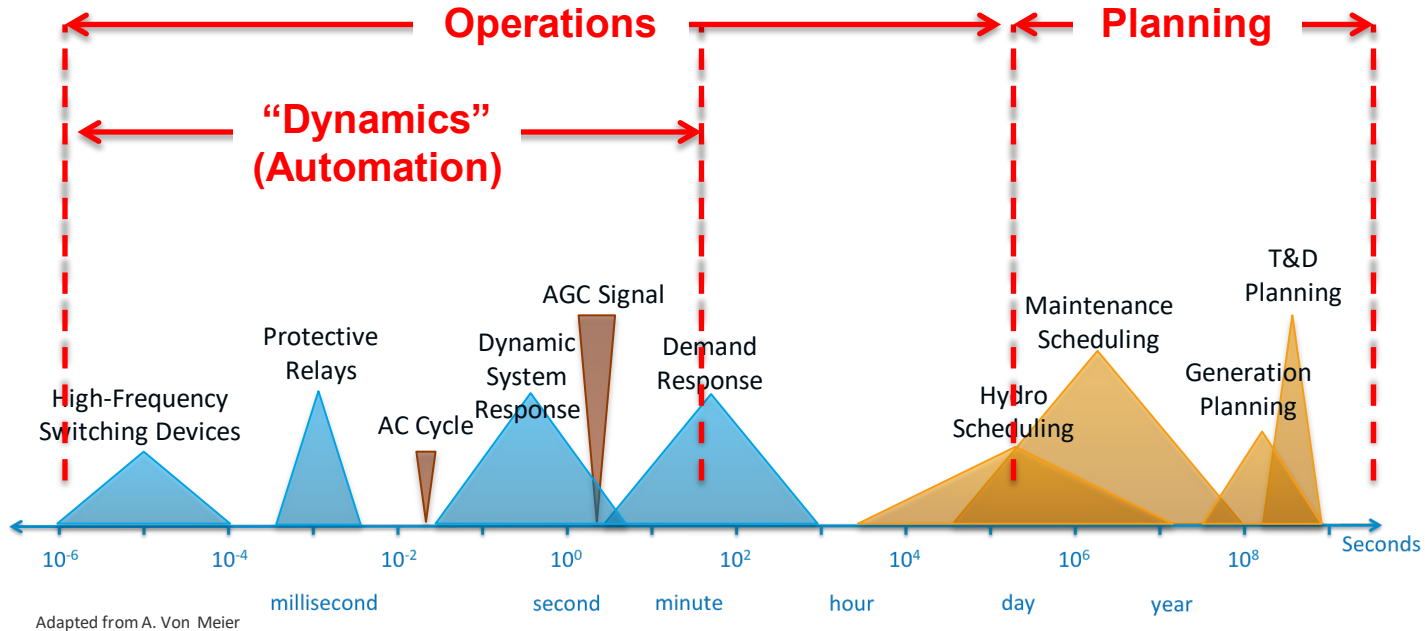
Relevant grid decision timescales

span 15 orders of magnitude



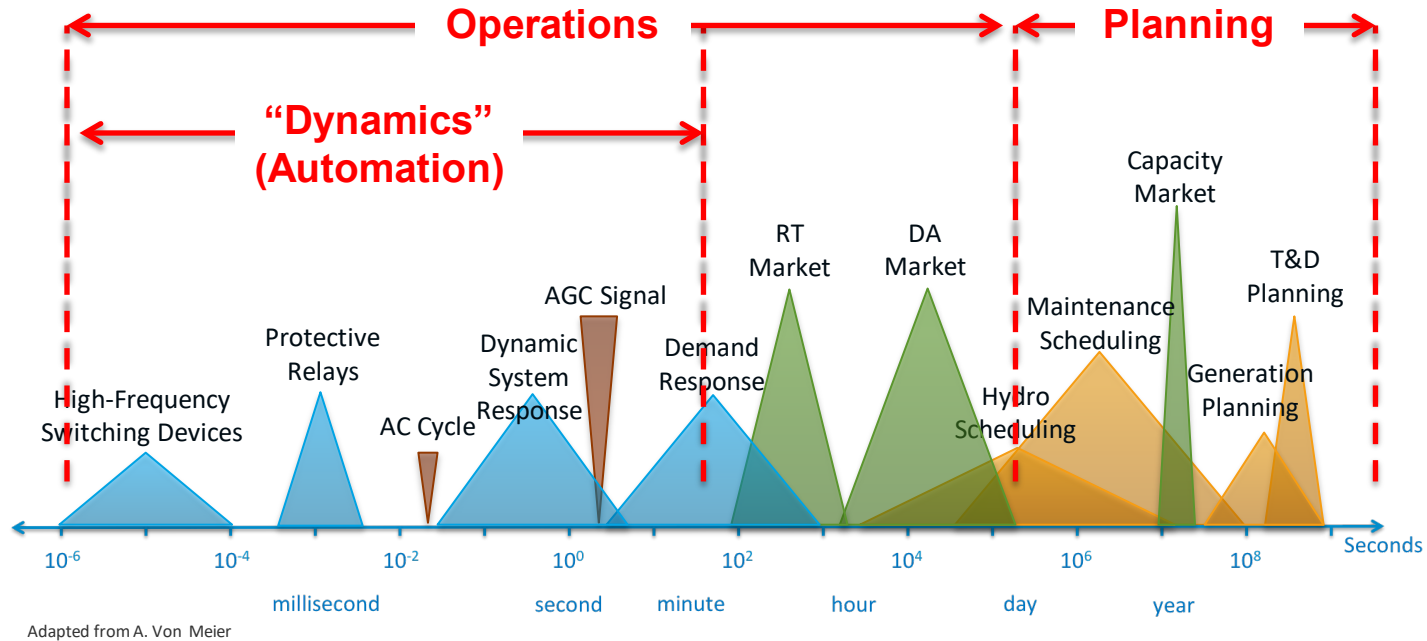
Relevant grid decision timescales

span 15 orders of magnitude



Relevant grid decision timescales

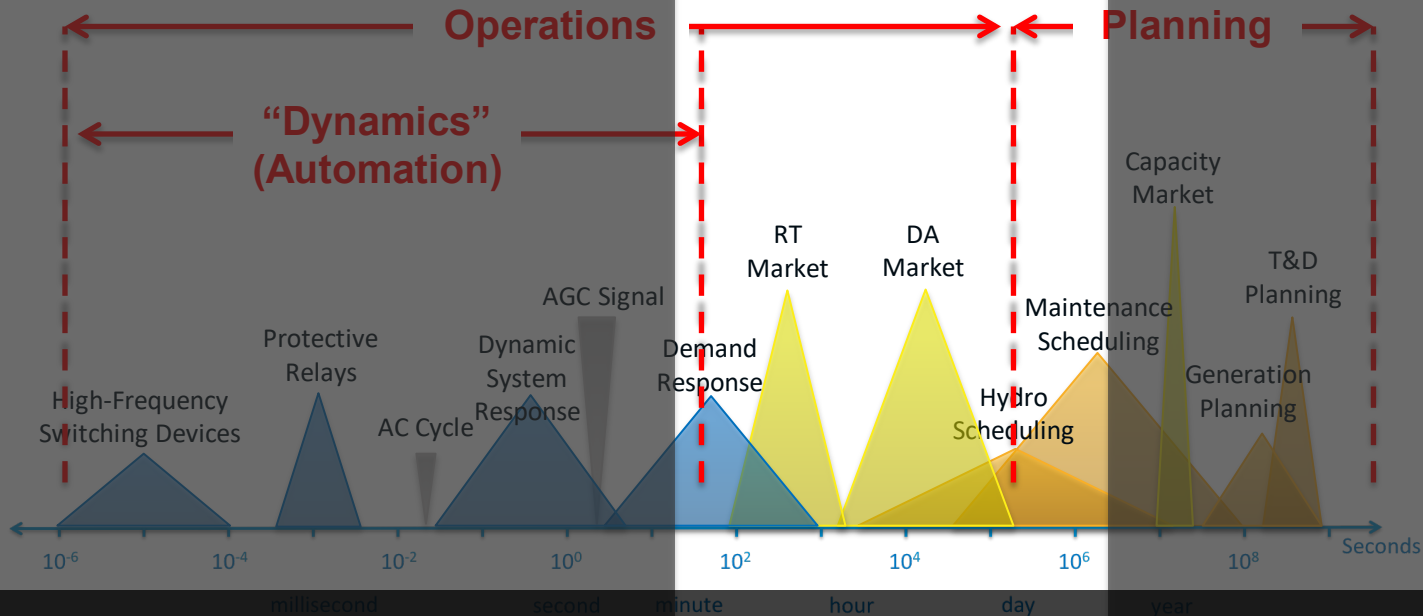
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Relevant grid decision timescales

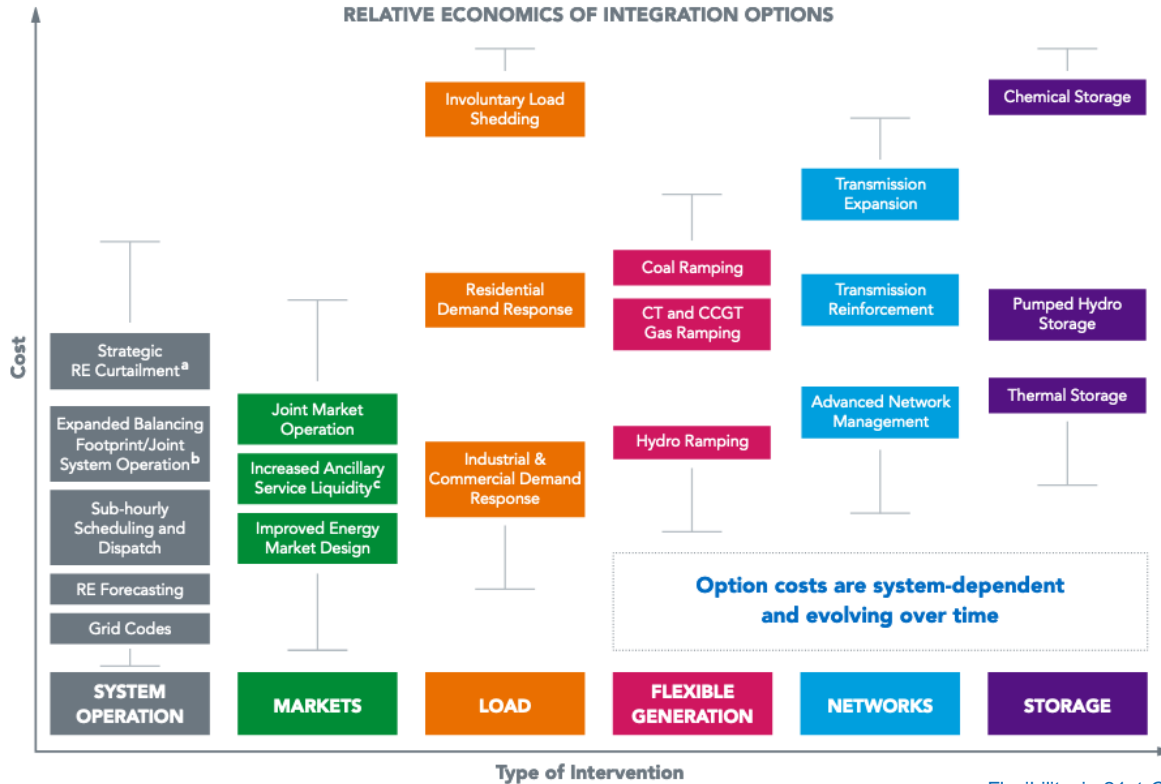
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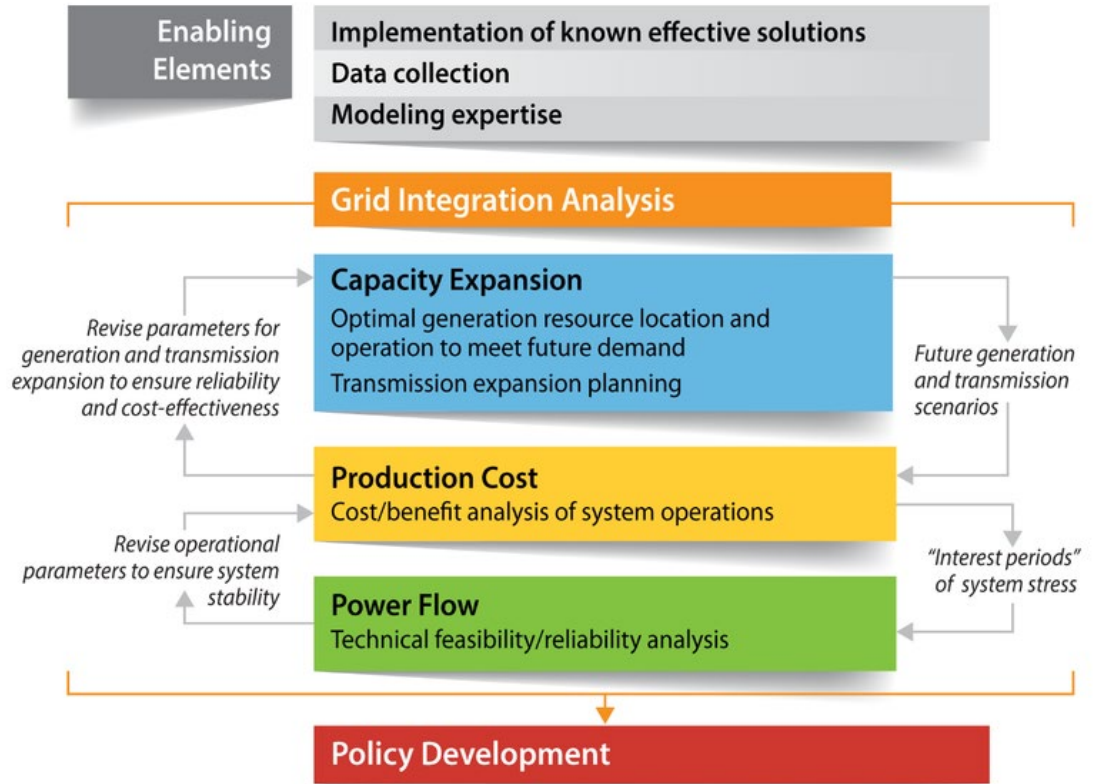
Production cost models (PCMs) simulate operations for planning

Sources of Flexibility



Introduction to Production Cost Modeling (PCM)

PCM for System Planning



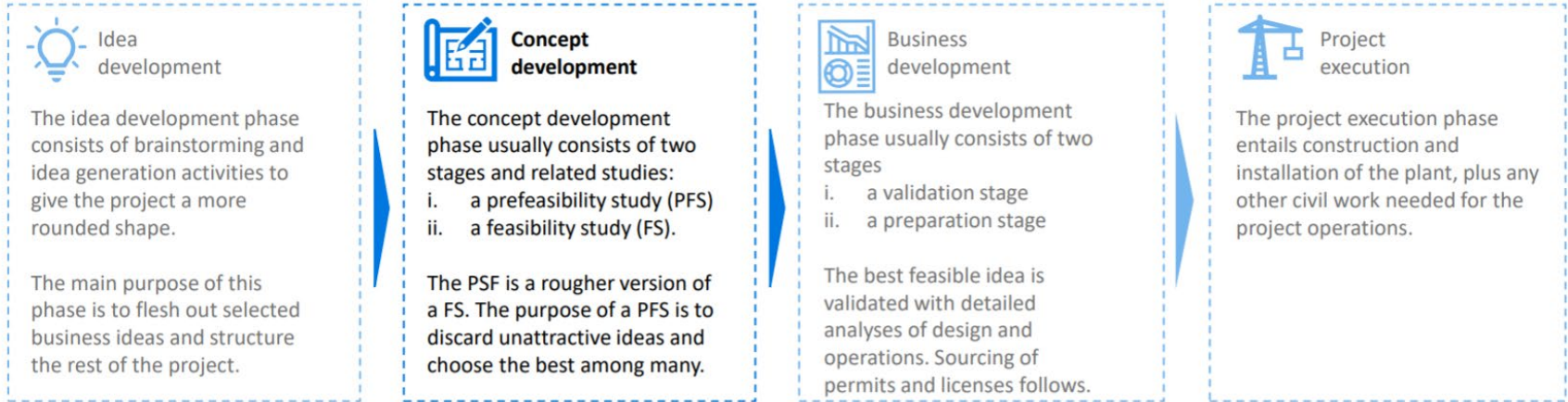
Example Outcomes: India Case Study

RE INTEGRATION STRATEGIES					
100 GW SOLAR 60 GW WIND					
NORMAL OPERATIONS	COORDINATED SCHEDULING AND DISPATCH		COAL PLANT FLEXIBILITY		
	REGIONAL	NATIONAL	LOWER MINIMUM PLANT GENERATION (40% of capacity)	HIGHER MINIMUM PLANT GENERATION (70% of capacity)	LOWER MINIMUM PLANT GENERATION (40% of capacity) WITH REGIONAL BALANCING AREA COORDINATION
STATE-LEVEL DISPATCH, 55% MINIMUM GENERATION					
230,000 INR Crore Annual Production Cost	2.8% Savings annually ↓	3.5% Savings annually ↓	Negligible Savings annually	0.90% Increased cost annually ↑	3.3% Savings annually ↓
1.4% Renewable energy curtailment	1.3% Renewable energy curtailment	0.89% Renewable energy curtailment	0.76% Renewable energy curtailment	3.5% Renewable energy curtailment	0.73% Renewable energy curtailment

FOR INTERNAL USE ONLY – DO NOT DISTRIBUTE. DO NOT CITE OR REFERENCE. This work is not for distribution or commercial purposes. The methodology, formula, and analysis used and presented in this document and the views herein do not necessarily represent the views of, nor are they endorsed by the U.S. Department of Energy or the U.S. Government, or any agency thereof.

[India Renewable Integration Study](#)

Developer Context: Project Development



The number of possible projects shrinks during the project development phase, as different options are assessed. One (or a subset) of initial ideas will go to execution.



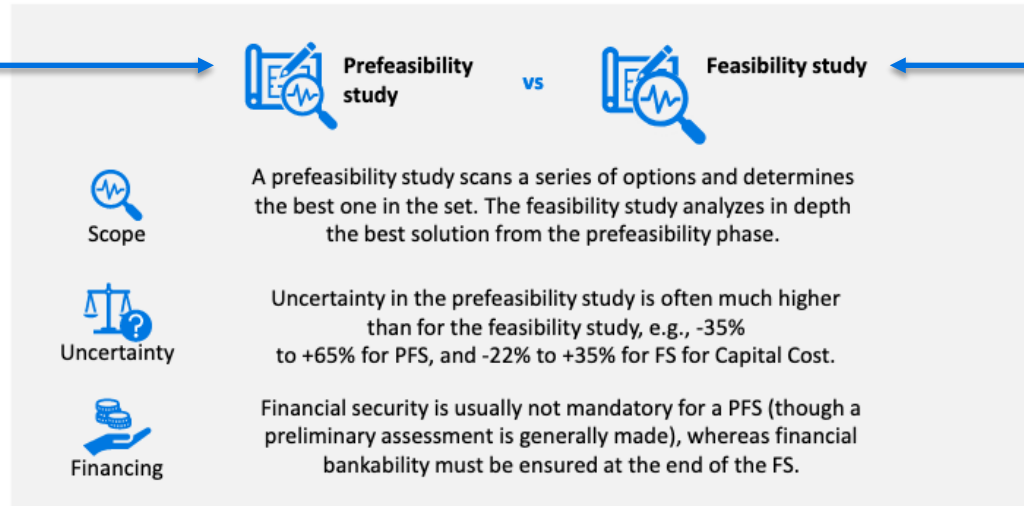
Source(s): [Danish Energy Agency Prefeasibility Study Guidelines](#)

Developer Context: Project Development



The concept development phase usually consists of two stages and related studies; a prefeasibility stage and study (PFS) and a feasibility stage and study (FS).

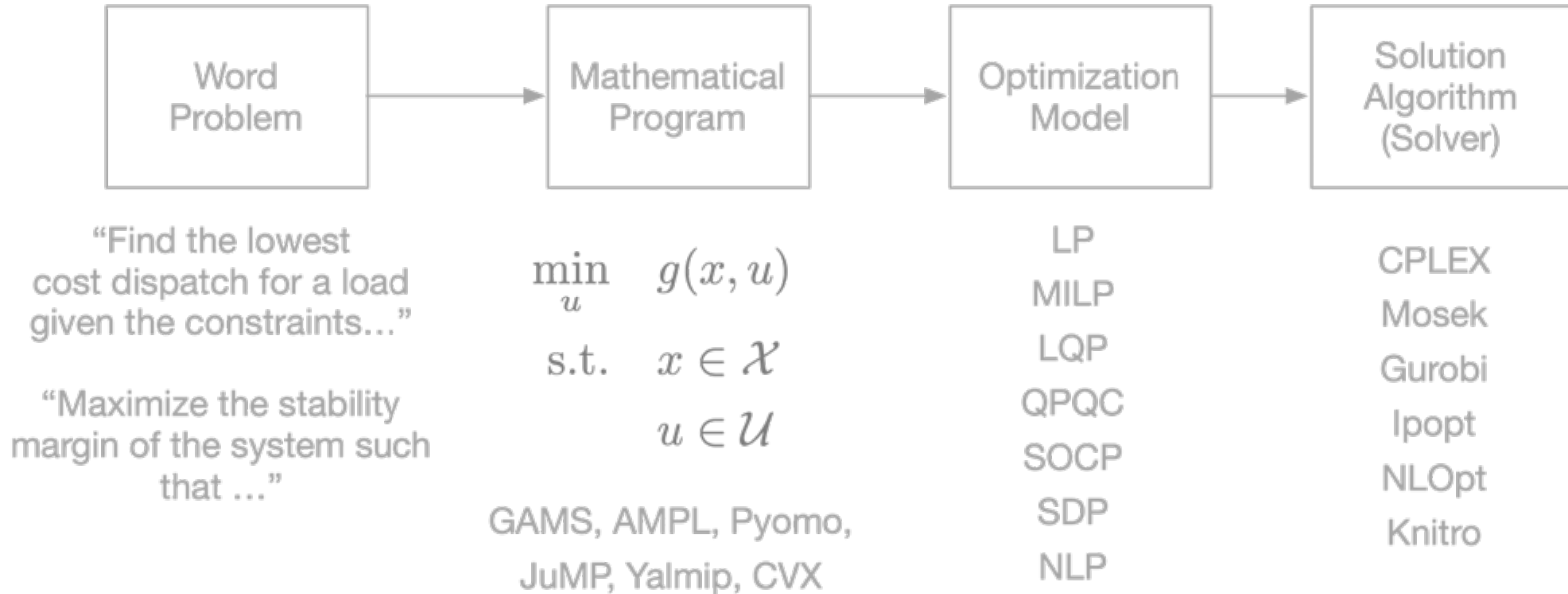
RE Data Explorer can aid prefeasibility study & resource prospecting



PCM can study impact of operations on project feasibility

- Bidding strategies
- Curtailement
- Local emissions displacement

Structure of an Optimization Problem



Building PCM Problems

Cost Function: Linear, Polynomial, Piece-wise Linear.

Device and Branch Level Model: Generator Limits, Storage Capacity, Branch Power Flow.

Network Model: Copper plate model or nodal flow balance.

Services Model: Reserves, Area Exchanges, Reactive Power Control Areas.

Feedforward Model: Reserves Commitments, Area Exchanges, Reactive Power Control Areas.



$$f^k(\cdot) = \min_{\vec{u}_t^k} C_{f_k}(\vec{u}_t^k)$$

$$\text{s.t. } H_{f_k}^D(\vec{u}_t, \vec{u}_{t-1}, \vec{x}_{t-1}, \vec{\rho}_t, \Phi^k | t) \leq 0$$

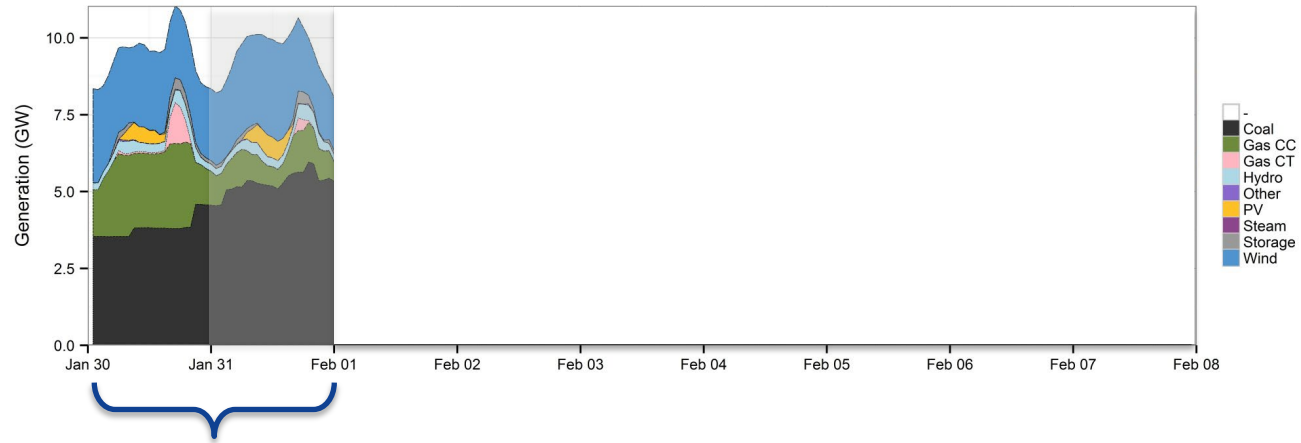
$$H_{f_k}^B(\vec{u}_t, \vec{u}_{t-1}, \vec{x}_{t-1}, \vec{\rho}_t, \Phi^k | t) \leq 0$$

$$H_{f_k}^N(\vec{u}_t, \vec{u}_{t-1}, \vec{x}_{t-1}, \vec{\rho}_t, \Phi^k | t) = 0$$

$$H_{f_k}^S(\vec{u}_t, \vec{u}_{t-1}, \vec{x}_{t-1}, \vec{\rho}_t, \Phi^k | t) \leq 0$$

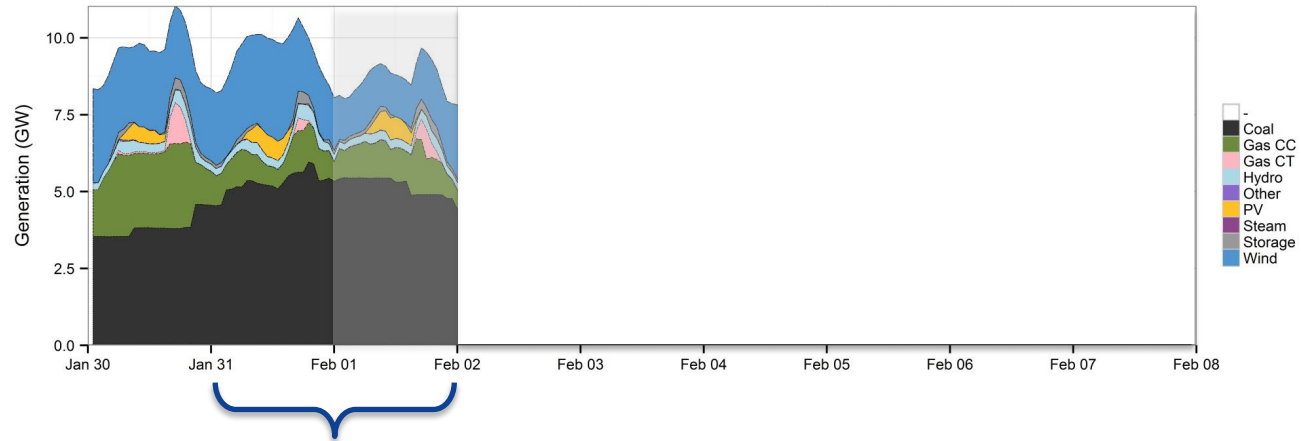
$$H_{f_k}^F(\vec{u}_t, \vec{u}_{t-1}, \vec{x}_{t-1}, \vec{\rho}_t, \Phi^k | t) \leq 0$$

Unit commitment and economic dispatch



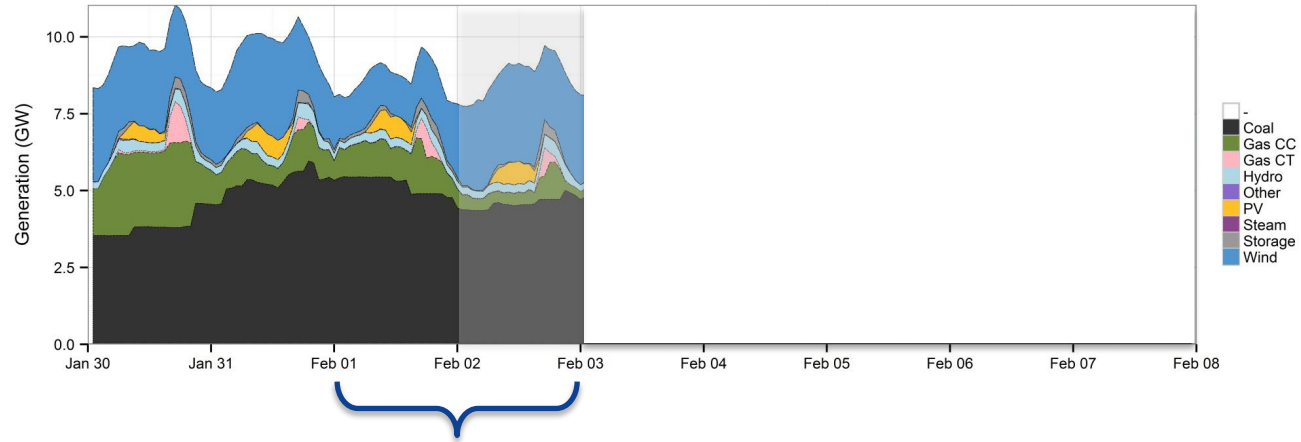
optimization horizon:
48 hours

Unit commitment and economic dispatch



rolling forward in
24 hour increments

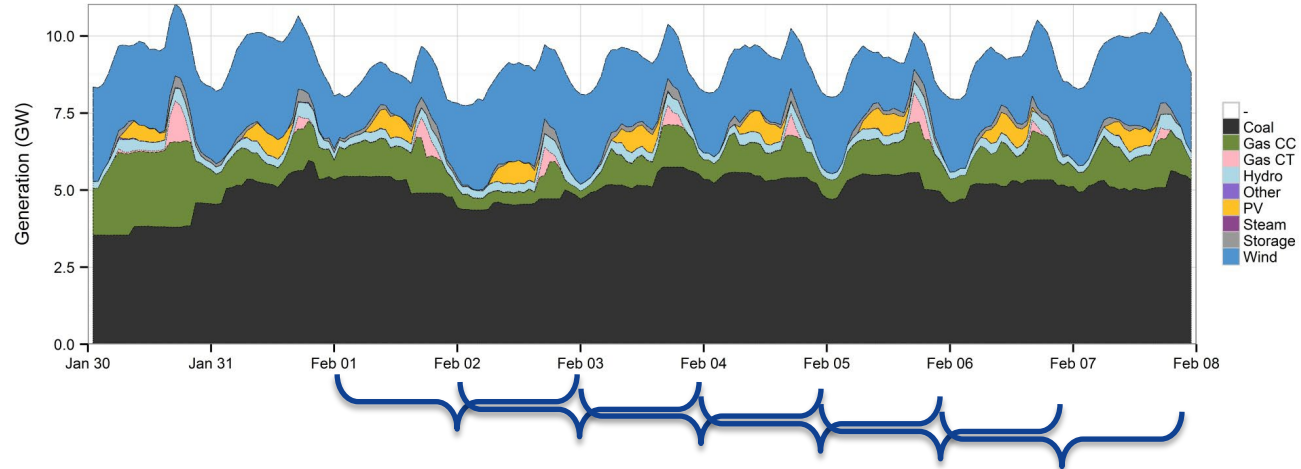
Unit commitment and economic dispatch



The state of the system at time $t=0$ is dependent on:

1. Generator commitment status: on/off
2. If “on”: hours of continuous operation; current ramp rate
3. If “off”: hours since last operation (minimum shut down duration)

Unit commitment and economic dispatch



- **Intertemporal Unit-Commitment & Economic Dispatch (UC/ED)**
Mixed Integer Programming problem (MIP)
- **Sequential UC/ED Steps**

Data Needs for PCM

See the [VRE Guidebook for Practitioners](#) (page 52) for a complete list of data requirements for PCM modeling.

Generator data:

- Bus location
- Minimum/maximum power levels
- Ramp limits
- Thermal plants:
 - Fuel type and heat rate curve
 - Minimum up time/down time
- Hydro plants:
 - Reservoir or river-flow data
- Storage plants:
 - Energy capacity
 - State-of-charge limits
- Eligible reserve categories
- Fuel cost data or market bids

System/operator data:

- Reserve categories and requirements

Transmission network data:

- Bus and branch topology
- Bus voltage level
- Line power flow limits
- Line reactance

Time-series data:

- Time-coincident load, wind, and solar time-series
 - Power data *or* resource data + a model
 - Hourly and/or sub-hourly resolution
 - Plant/bus, zonal, or area spatial resolution
- Require 2 time-series data sets to model forecast uncertainty using UC/ED:
 1. Forecast posted day-ahead, hour-ahead, 5-minute-ahead, etc.
 2. Realizations

Open-Source Data for PCM

Historical time-series data:

- [RE Data Explorer](#) Southeast Asia Wind data, Asia/Pacific Himawari and Puerto Rico Solar data
- [National Solar Radiation Database \(NSRDB\)](#)
- [Wind Integration National Dataset Toolkit](#) (North America)
- System operators often post historical hourly demand (for example, [National Grid Corporation of the Philippines Operations Data](#))

Historical and real-time weather forecasts:

- [European Centre for Medium-Range Weather Forecasts](#)

Cost data:

- [NREL Annual Technology Baseline](#) (US)

Transmission network data:

- [BetterGrids](#)
- [DR POWER](#)
- [openmod](#)
- [Texas A&M University synthetic networks](#)

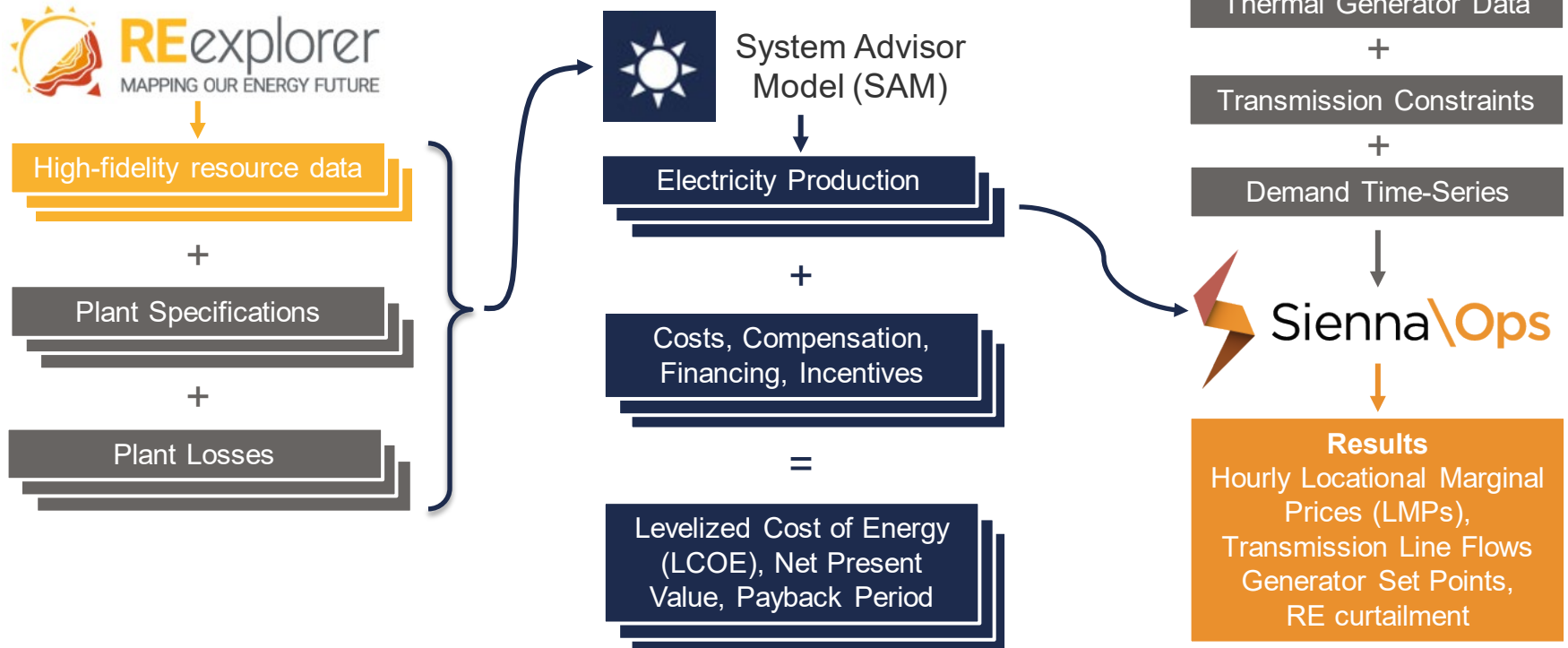
Plant operating characteristics:

- [World Resources Institute Global Power Plant Database](#)
- Industry and academic publications, such as [IRENA's Flexibility in Conventional Power Plants brief](#)
- US EPA [National Electric Energy Data System \(NEEDS\)](#)
- US EIA [Form 923](#) and [Form 923](#)

Open-Source Tools for PCM Development

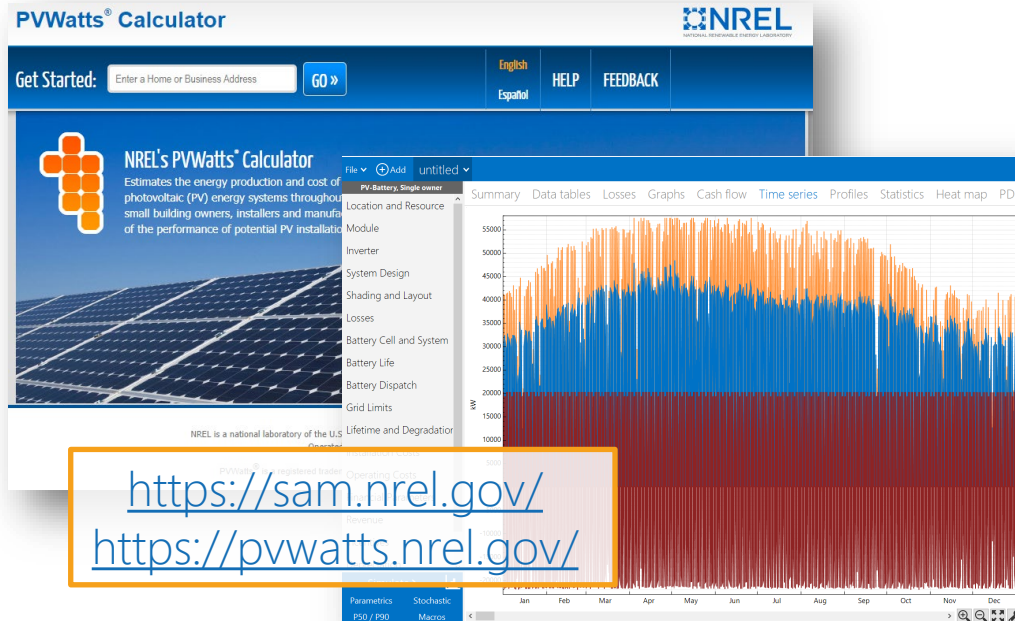
NREL System Advisor Model (SAM) and Sienna

Today's Workflow



System Advisor Model (SAM)

Free software that enable detailed performance and financial analysis for renewable energy systems



<https://sam.nrel.gov/>
<https://pwwatts.nrel.gov/>

- ✓ Open-source code
- ✓ Extensive documentation and user support
- ✓ Evaluate financial metrics for different markets
- ✓ Parametric and uncertainty analysis
- ✓ View and export key results



Overview of SAM Capabilities

Technologies

- Photovoltaics
- Battery Storage
- Wind power
- Concentrating solar power
- Marine energy and tidal systems
- Fuel cells
- Geothermal
- Biomass
- Solar water heating

Financial Models

- Behind-the-meter
 - Residential, Commercial
 - Third-party ownership
- Power purchase agreements
 - Single owner
 - Equity flips
 - Sale-leaseback
- Merchant plants
- Simple LCOE calculator

Accessing SAM

Online through the PVWatts® Calculator

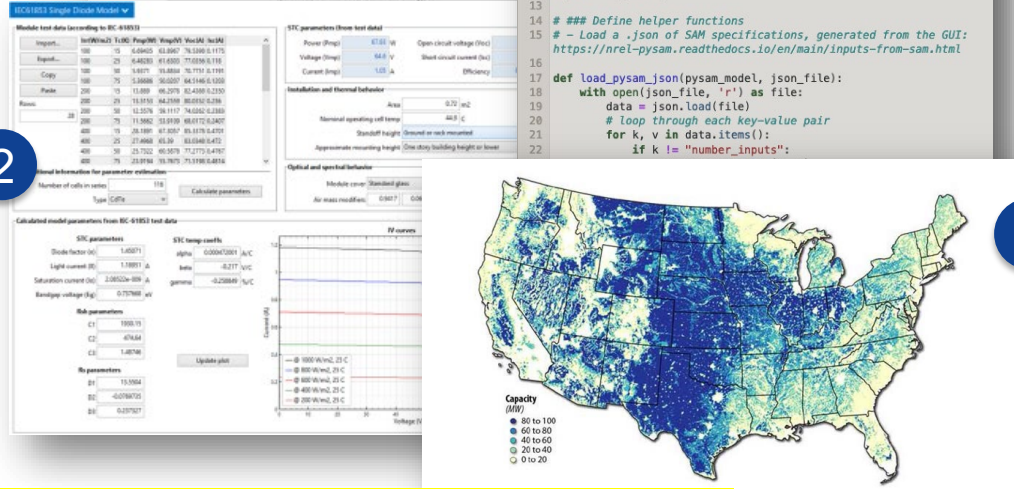
- For quick ballpark calculations



2

Download the GUI

- For detailed modeling of individual plants



3

Programmatically

- To develop your own application around SAM or run SAM through Python

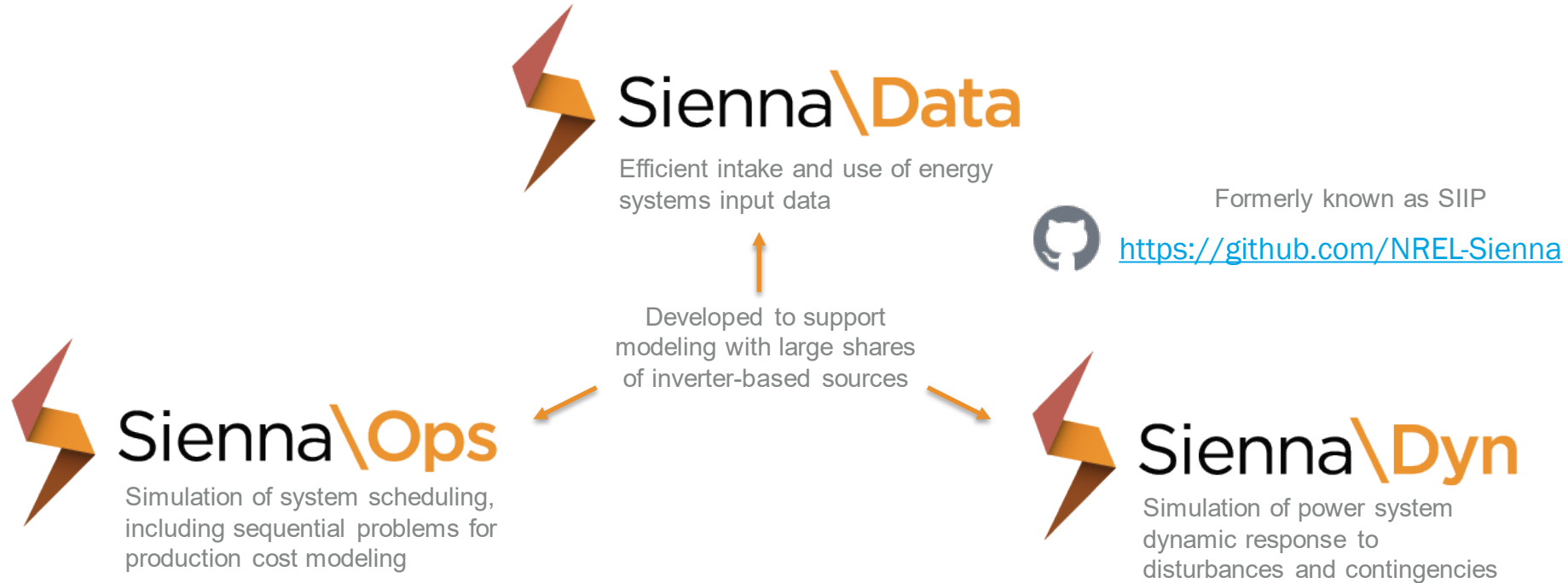
```
1 #!/usr/bin/env python
2 # coding: utf-8
3
4 # This code takes the time-series wind and solar resource profiles
5 # from the RE-Data Explorer and processes them into power profiles
6 # to use in time-series simulations in PowerSimulations.jl.
7
8 import PySAM.PvwattsV8
9 import PySAM.Windpower
10 import os
11 import glob
12 import json
13 import pandas as pd
14 import numpy as np
15
16 ### Define helper functions
17 # - Load a .json of SAM specifications, generated from the GUI:
18 # https://nrel-pysam.readthedocs.io/en/main/inputs-from-sam.html
19
20 def load_pysam_json(pysam_model, json_file):
21     with open(json_file, 'r') as file:
22         data = json.load(file)
23         # loop through each key-value pair
24         for k, v in data.items():
25             if k != "number_inputs":
```

4

Through reV, the Renewable Energy Potential Model

- For very large batch processing and scenario development

Open-source ecosystem for power system modeling, simulation and optimization

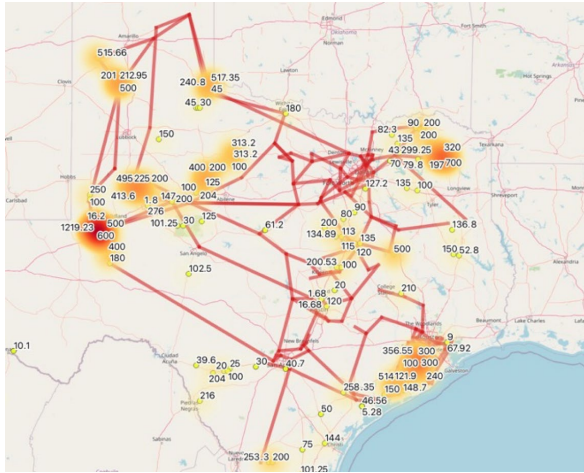


Sienna in Julia

Sienna's three core applications use combinations of packages in the [Julia Programming Language](#)

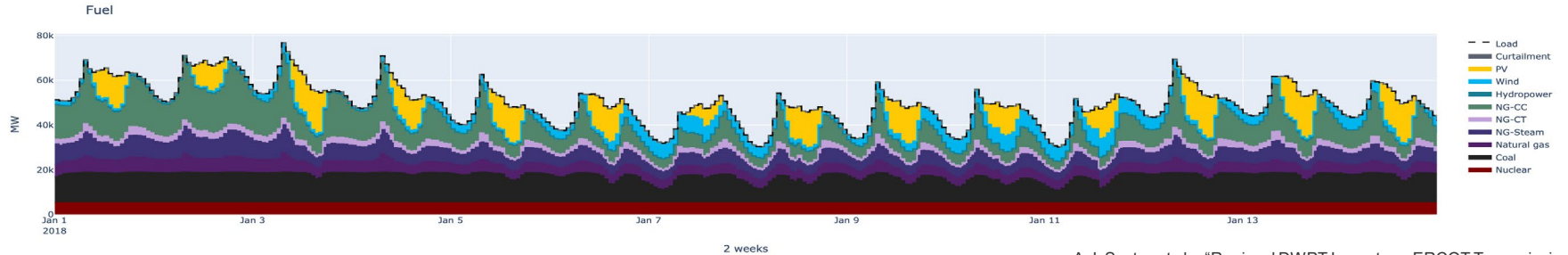


Sienna\Ops: PCM for Large Systems



Generator Type	Installed Capacity Original System [MW]	Installed Capacity Modified System [MW]
PV	938.04	21,031.9
Gas Turbines	76,572.1	76,572.1
Steam Turbines	23,568.2	23,568.2
Hydro	1,326.72	15,81.22
Wind Power	15,089.0	14,755.4

The system achieves up to 45% instant penetration of solar power at certain hours of the day.

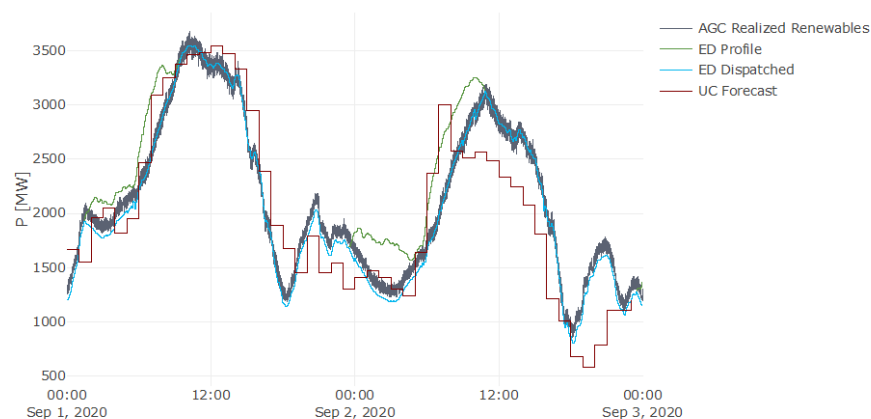
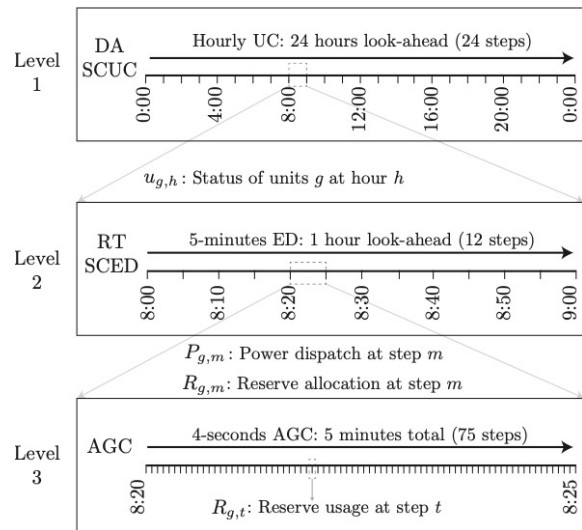


A.J. Sauter et al. . "Regional DWPT Impacts on ERCOT Transmission System and Operation Cost." Submitted to Applied Energy

Automatic Generation Control

How effective are reserve requirements, market designs, and generator controls at handling wind, solar, load, and generator availability forecast errors to maintain supply/demand balance?

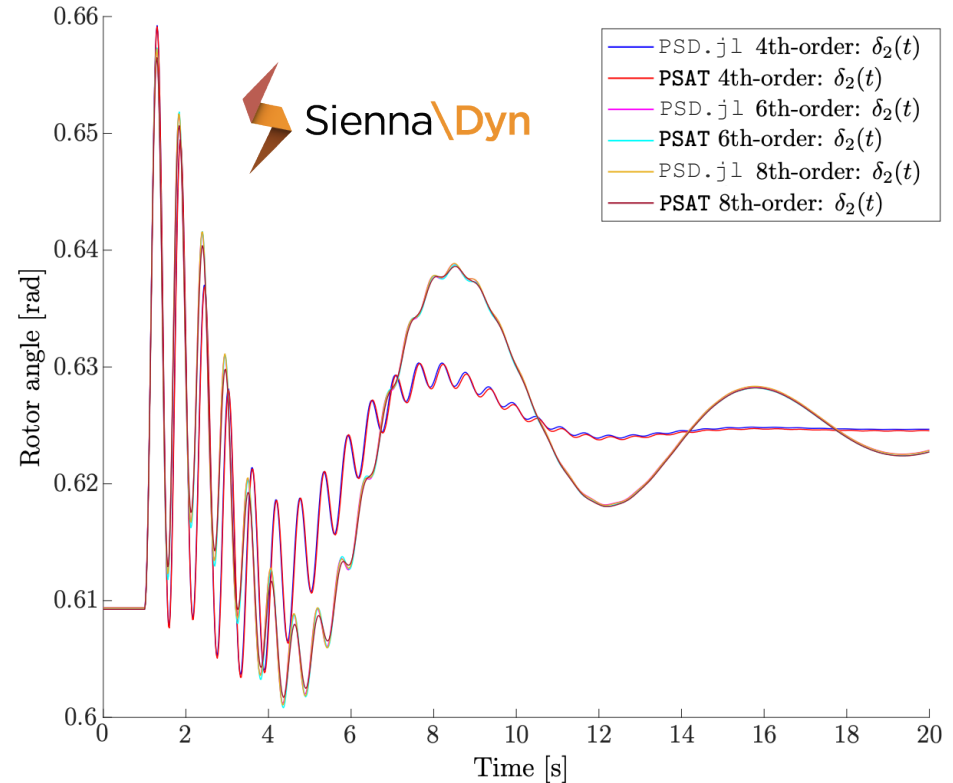
- Enables the assessment of system reliability
- Improves upon the scalability and PCM integration of existing state-of-the-art
- System performance evaluation capabilities
 - Reserve product adequacy
 - Ancillary service provision from emerging technologies
 - Forecasting techniques
 - Market design



Transient Stability phasor EMT

Is the system stable against perturbations from setpoint transitions, fluctuations in generator and demand injections, and contingencies?

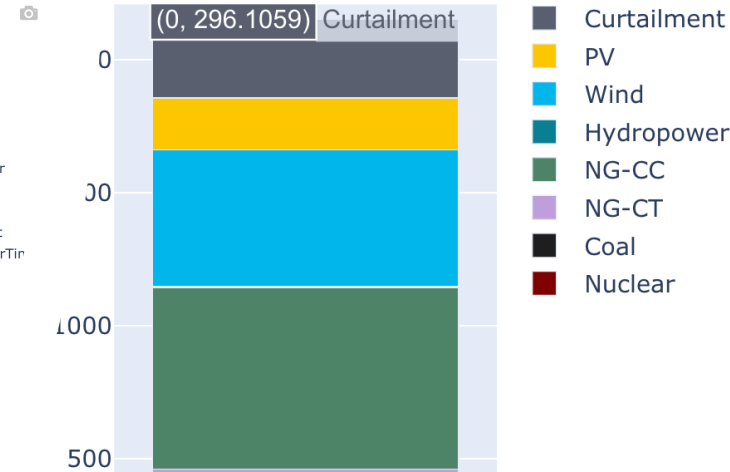
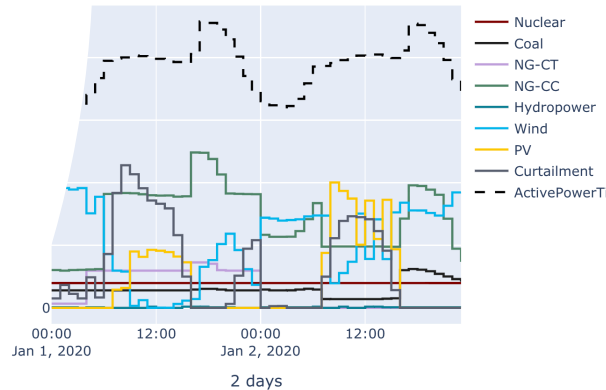
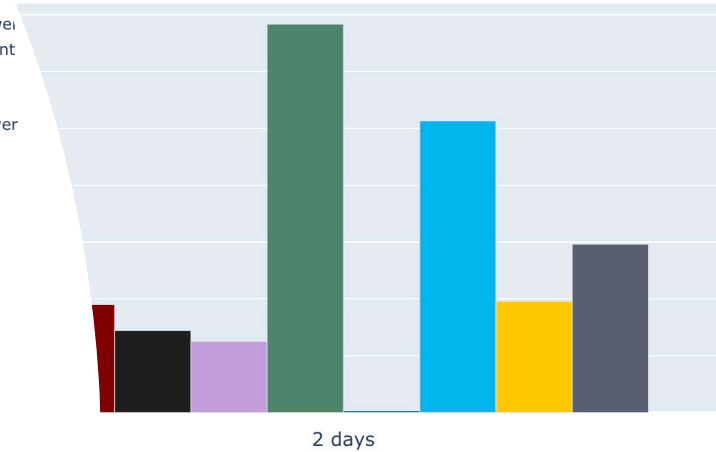
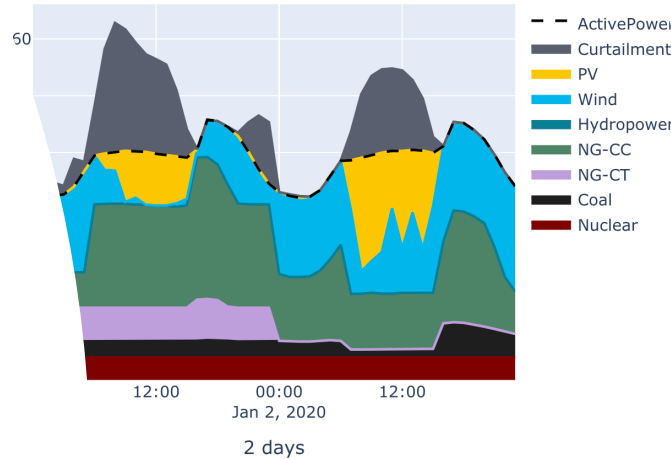
- Existing commercial tools can address these questions for select models and under a fix set of solution algorithms.
- Sienna\Dyn provides a scalable solution (open-source) to assess stability under evolving (low-inertia) grid conditions.



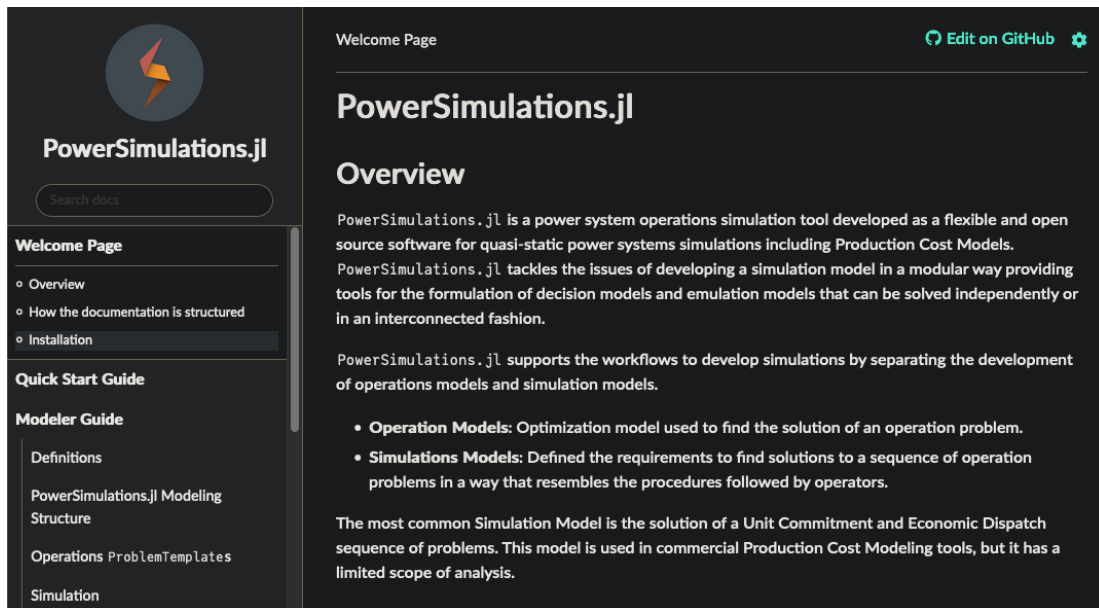
Visualizations with PowerGraphics.jl


- **Plot types:** bar, stack, line, (coming soon: networks)
- **Data:** System, Operations results, (coming soon: dynamics results)
- **Backends:** GR (static), PlotlyJS (basic interactivity)

Fuel



Sienna Resources



Welcome Page [Edit on GitHub](#) 

PowerSimulations.jl

Search docs

- Welcome Page
 - Overview
 - How the documentation is structured
 - Installation
- Quick Start Guide
- Modeler Guide
 - Definitions
 - PowerSimulations.jl Modeling Structure
 - Operations ProblemTemplates
 - Simulation

Overview

PowerSimulations.jl is a power system operations simulation tool developed as a flexible and open source software for quasi-static power systems simulations including Production Cost Models. PowerSimulations.jl tackles the issues of developing a simulation model in a modular way providing tools for the formulation of decision models and emulation models that can be solved independently or in an interconnected fashion.

PowerSimulations.jl supports the workflows to develop simulations by separating the development of operations models and simulation models.

- Operation Models:** Optimization model used to find the solution of an operation problem.
- Simulations Models:** Defined the requirements to find solutions to a sequence of operation problems in a way that resembles the procedures followed by operators.

The most common Simulation Model is the solution of a Unit Commitment and Economic Dispatch sequence of problems. This model is used in commercial Production Cost Modeling tools, but it has a limited scope of analysis.

Package documentation includes Quick Start Guides and Tutorials:

- [PowerSystems.jl](#)
- [PowerSimulations.jl](#)
- [PowerSimulationsDynamics.jl](#)
- [PowerGraphics.jl](#)

NREL Team: sienna@nrel.gov

Slack: <https://nrel-sienna.slack.com>

Other Open-Source Planning Tools

Production cost modeling:

- GridPath

Capacity Expansion:

- Caliope/Engage
- Switch
- GenX.jl
- ReOpt
- PyPSA

Load flow:

- MATPOWER
- PANDAPOWER
- PowerModels.jl

Dynamics:

- Sienna\Dyn
(PowerSimulationsDynamics.jl)
- ANDES
- PowerDynamics.jl
- Dynawoo

Distribution scale:

- OpenDSS
- GridLab-D
- PowerModelsDistribution.jl

See <https://g-pst.github.io/tools/>

Synthesis and Wrap-Up

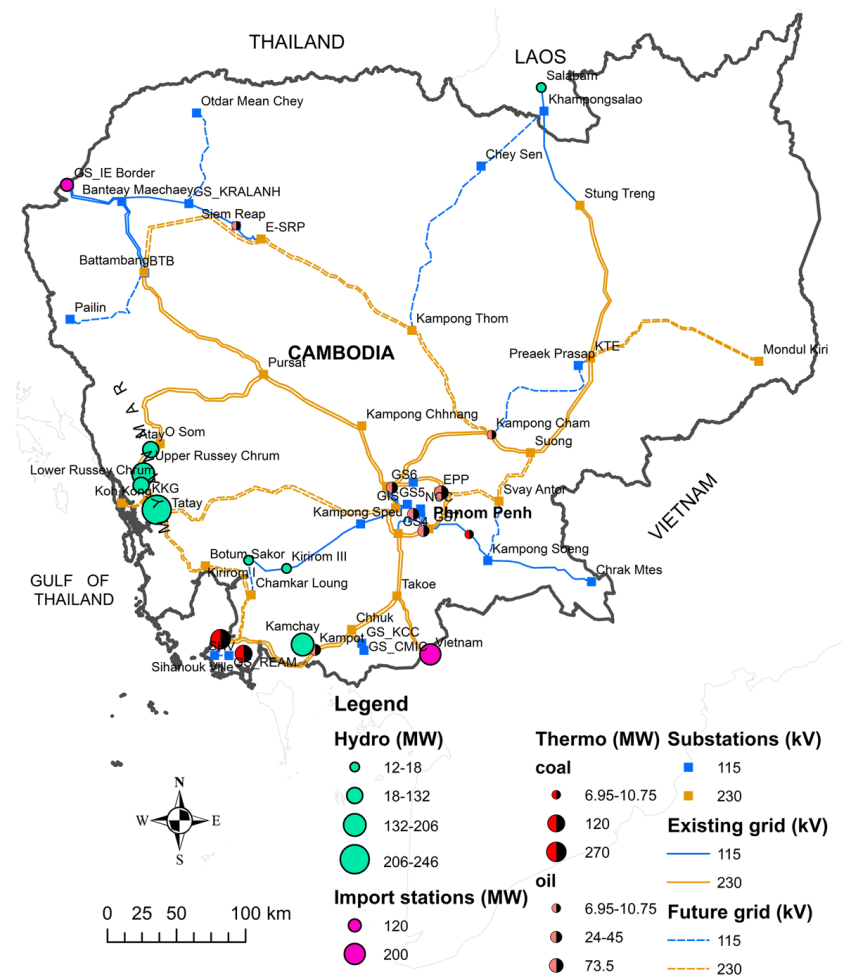
Key Takeaways

- Power system *flexibility* is key for integrating VRE
- Time-series production cost modeling can quantify the benefits of many sources of operational flexibility
- For system operators, PCM is key to operations and planning:
 - Minimize operating & reserve costs on a daily, hourly, subhourly basis
 - Study & anticipate impacts of VRE scenarios on operations
- For developers, PCM can help determine site feasibility:
 - Transmission-constrained curtailment, market bidding strategies (hybrid/storage), locational cost and emissions impacts
- Open-source data and models reduce cost and difficulty of site prefeasibility and feasibility studies

Case Study: Cambodia

PowNet (2021):

- Open-source, hourly-resolution operational model
- Includes transmission lines and generators
- <https://github.com/Critical-Infrastructure-Systems-Lab/PowNet>



Next Session

- 1 Recap of Day 1
- 2 Overview of PCM Workflow and Sample Analysis
- 3 Resource Visualization and Site Screening in RE Data Explorer
- 4 PCM Demonstration in Sienna\Ops
- 5 Open-Source Training Resources
- 6 Audience Q&A
- 7 Wrap Up

Preparing for Tomorrow's Session (Optional)

- The code for the case study production cost modeling demonstration is available on Github: <https://github.com/NREL-Sienna/PSI-Cambodia>
- An explanation of the demonstration is available in the [PSI-Cambodia README](#), including some of the installation instructions below.
- **Instructions for installing software for the three open-source tools we will be using:**
 1. RE-Data Explorer: [Can be accessed online](#) without any installation
 2. System Advisor Model (SAM): We will run SAM in Python using the PySAM wrapper, as well as designing plant specifications in the SAM GUI:
 1. [Download the SAM GUI](#)
 2. [Install Python](#)
 3. Activate the environment as described in the [PSI-Cambodia README](#) (step 2.c in the README)
 3. Sienna: Sienna is written in the Julia programming language
 1. [Install Julia](#)
 2. Activate the environment and run `literate.jl` as described in the [PSI-Cambodia README](#) (step 3 in the README)
- **For more information, visit [Variable Renewable Energy Grid Integration Studies: A Guidebook for Practitioners](#).**

You can visit these resources at:

<https://globalpst.org/transforming-the-global-power-sector-open-data-and-tools-for-renewable-energy-integration/>

Q&A

Thank you!
