U.S. Department of Energy

HelioCon

Heliostat Consortium for Concentrating Solar-Thermal Power

A Performance Forecasting Framework for Concentrating Solar Power Systems

Presented by Alex Zolan[1], ASME ES Conference 2023

Additional Contributors: Jeremy Sment[2], Chad Augustine[1], Guangdong Zhu[1]

[1]National Renewable Energy Laboratory, Golden, CO, United States

[2]Sandia National Laboratories, Albuquerque, NM, United States

conceptional design • components • integration • mass production • heliostat field

What we describe in this talk

- We summarize a methodology used to characterize the uncertainty in performance of a contrived CSP project
- We develop a case study in which we backcast the projected and actual annual performance of an existing plant
- We highlight the importance of several assumptions and the use of time series inputs in obtaining realistic estimates

Motivation

- Many performance characterization tools include highly detailed models of system performance to provide estimates
- In design optimization, the problem framing attempts to maximize production, or what a plant ***could*** do
- Operators wish to minimize downtime and outages, a different objective, but the rules they obey inform what a plant ***will*** do
- This presentation is an attempt to **start** bridging that gap when estimating output

Heliostats in Solar Field 1 of Ivanpah Solar Generating Facility

Key sources of uncertainty

Direct Normal Irradiance

- Variability in resource from year to year
- Measurement error in process

Receiver Heat Loss

- Convection due to wind (variable, difficult to quantify and monitor)
- Radiosity (radiation and reflection)

Power Plant Outages

- Scheduled maintenance
- Repair of failed components

Solar Field Outages

- Wind stow events
- Communications system failures
- Receiver maintenance

Modeling Error

- Optical performance (analytical vs. ray tracing)
- System performance inputs (efficiencies, etc.)

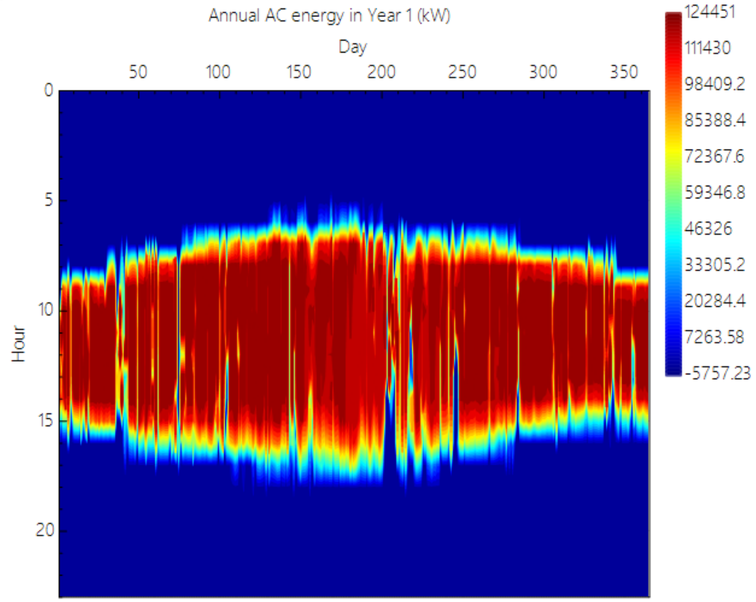
Heliostat Performance and Availability

- Reflectance in response to soiling, cleaning schedule
- Failures of individual heliostats and repairs
- Optical error, including wind impacts

Central software tool: System Advisor Model

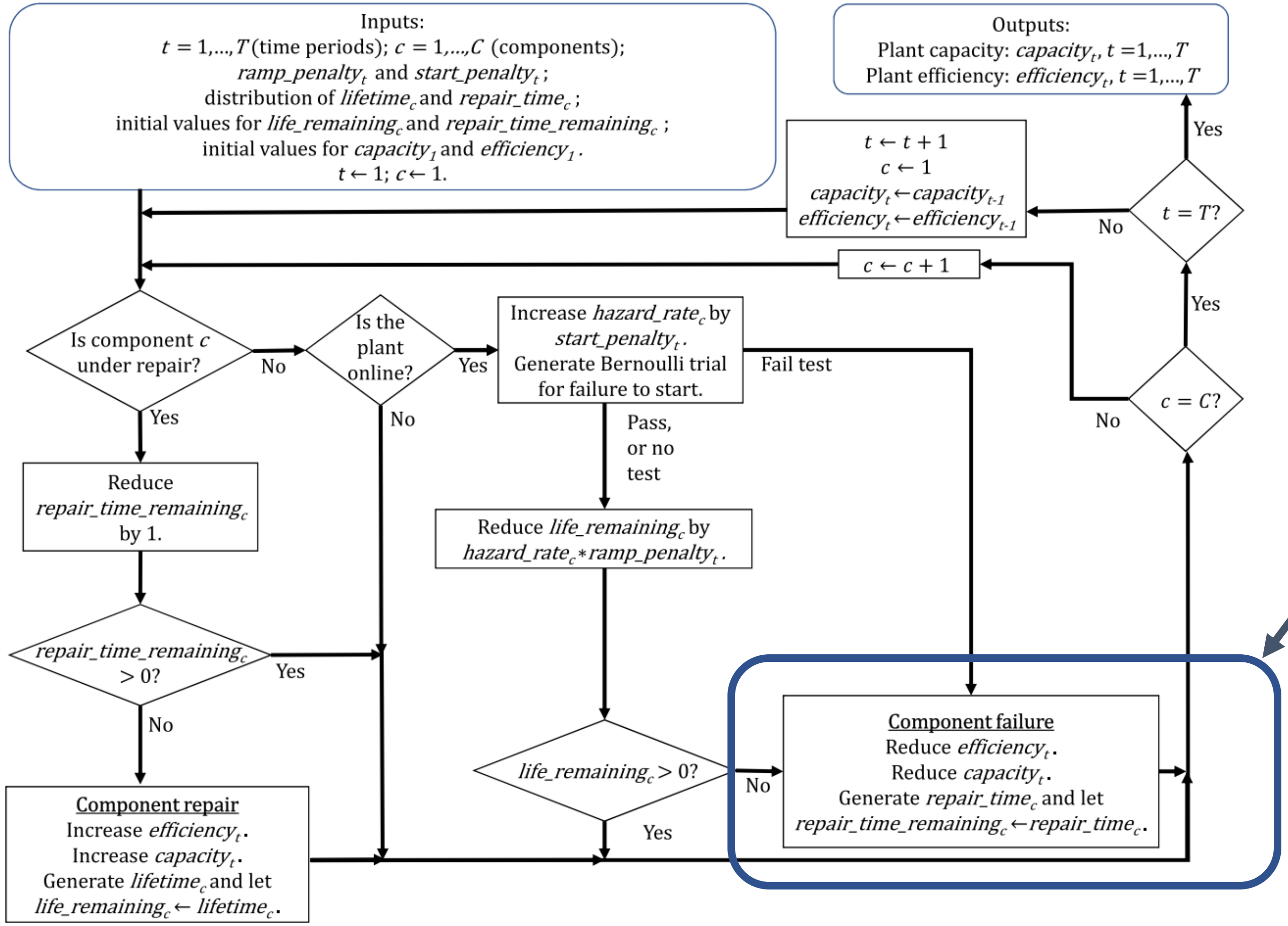
- Performance characterization model accepts time-series inputs for subsystem availability
  - Default is a constant multiplier for all hours in most cases
- Includes plug-in for dispatch optimization, which we don't use (yet)

Metric	Value
Annual AC energy (year 1)	288,117,440 kWh
Capacity factor (year 1)	28.0%
Annual Water Usage	52,592 m^3
PPA price in Year 1	8.40 ¢/kWh
PPA price escalation	1.00 %/year
LPPA Levelized PPA price nominal	9.06 ¢/kWh
LPPA Levelized PPA price real	7.27 ¢/kWh
LCOE Levelized cost of energy nominal	16.26 ¢/kWh
LCOE Levelized cost of energy real	13.05 ¢/kWh
NPV Net present value	$-192,093,952
IRR Internal rate of return	-9.58 %
Year IRR is achieved	20
IRR at end of project	-4.88 %
Net capital cost	$524,412,672
Equity	$420,388,992
Size of debt	$104,023,664
Debt percent	19.84%



Example summary and time-series output from System Advisor Model instance

Power plant outage simulation method

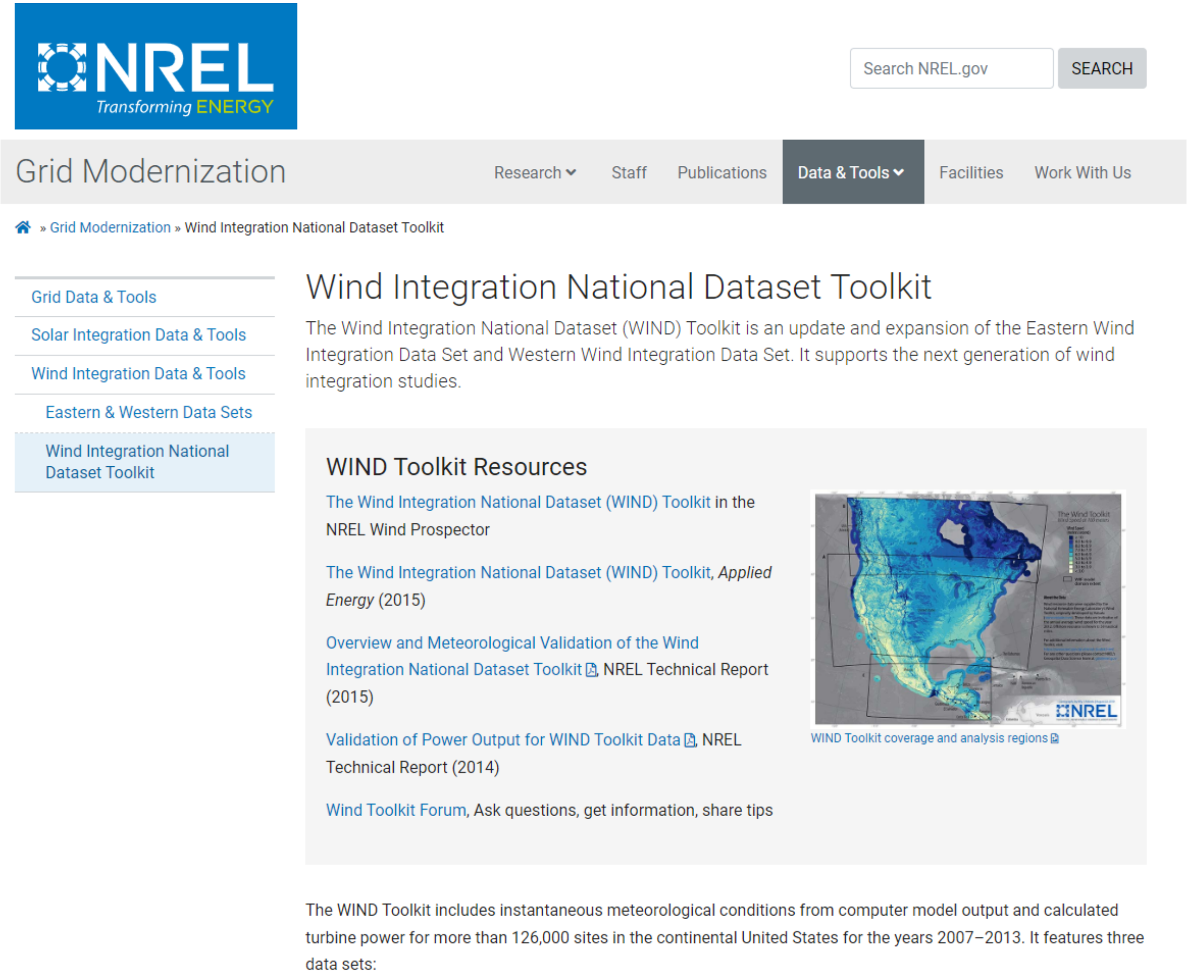


Component Failures can be caused by exceeding lifetime (running hours) or fail-to-start (Bernoulli) trials, using existing (nuclear) industry-provided distributions for component reliability

- Source paper: Combining simulation and optimization to derive operating policies for a concentrating solar power plant | SpringerLink

Wind-induced outages: Source data

- We will use high-fidelity data from this database and the thresholds for operation at an existing plant to determine outages
- For forecasts, we can use summary statistics using multiple years of data to obtain seasonal rates of failures and simulate out-year scenarios



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Wind Integration National Dataset Toolkit

The Wind Integration National Dataset (WIND) Toolkit is an update and expansion of the Eastern Wind Integration Data Set and Western Wind Integration Data Set. It supports the next generation of wind integration studies.

WIND Toolkit Resources

The Wind Integration National Dataset (WIND) Toolkit in the NREL Wind Prospector

The Wind Integration National Dataset (WIND) Toolkit, *Applied Energy* (2015)

Overview and Meteorological Validation of the Wind Integration National Dataset Toolkit NREL Technical Report (2015)

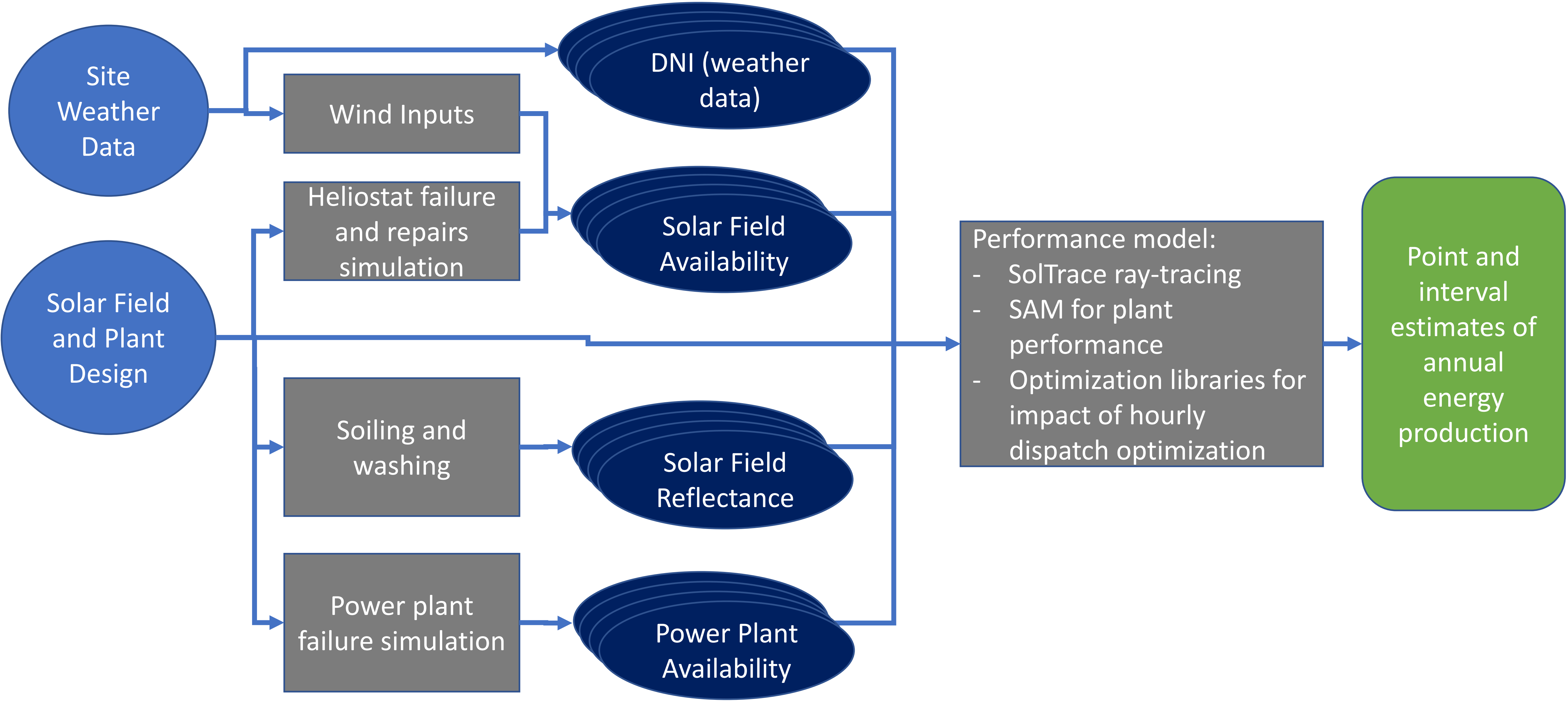
Validation of Power Output for WIND Toolkit Data NREL Technical Report (2014)

Wind Toolkit Forum, Ask questions, get information, share tips

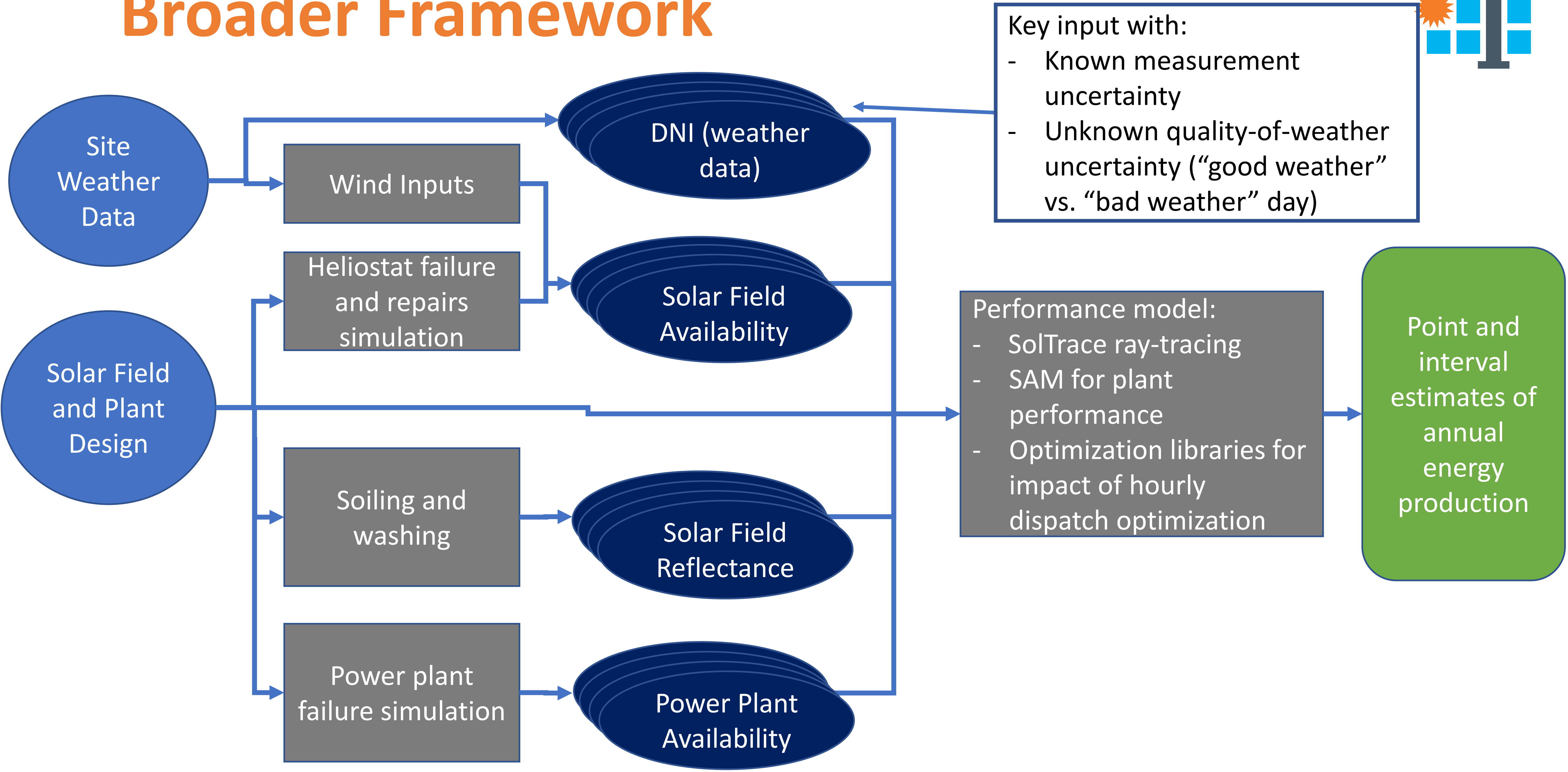
WIND Toolkit coverage and analysis regions

The WIND Toolkit includes instantaneous meteorological conditions from computer model output and calculated turbine power for more than 126,000 sites in the continental United States for the years 2007–2013. It features three data sets:

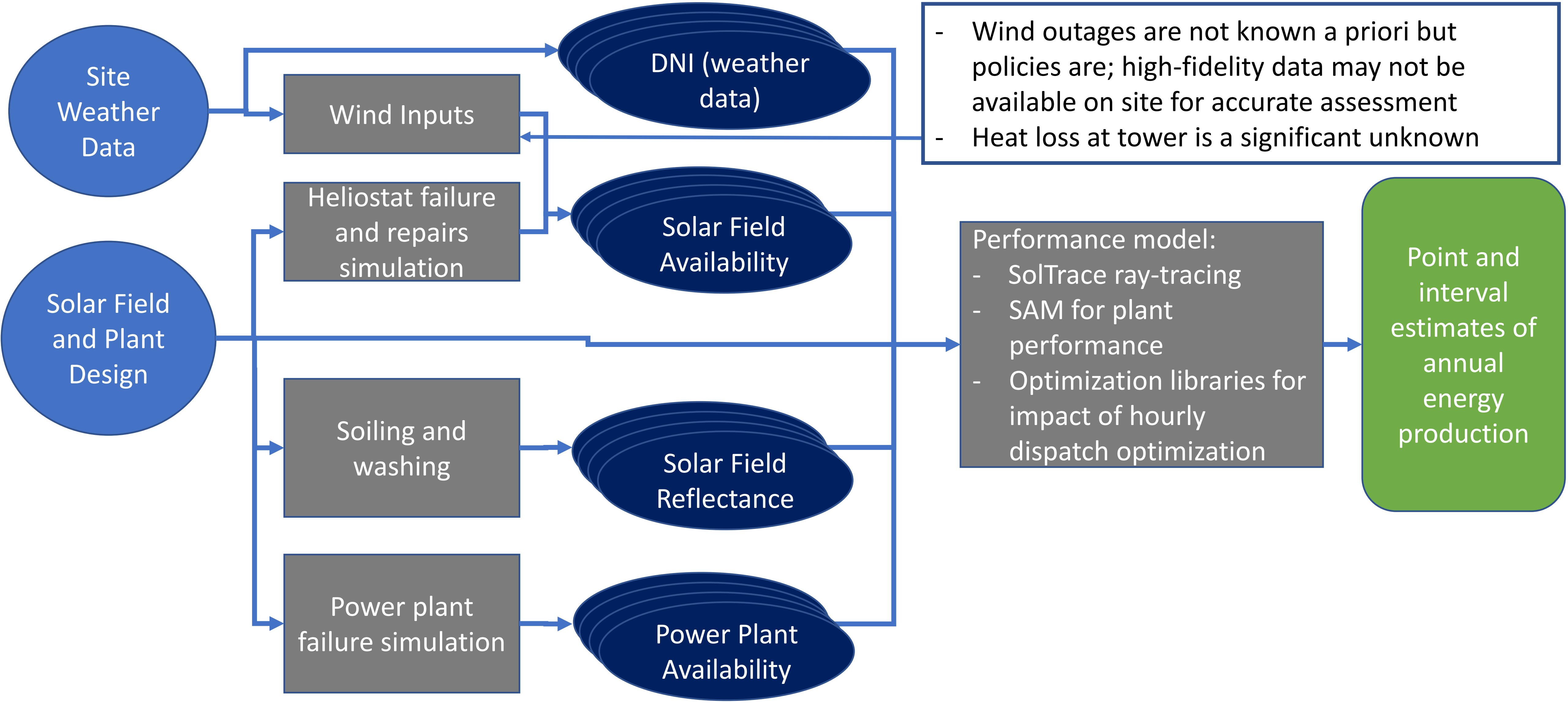
Broader Framework



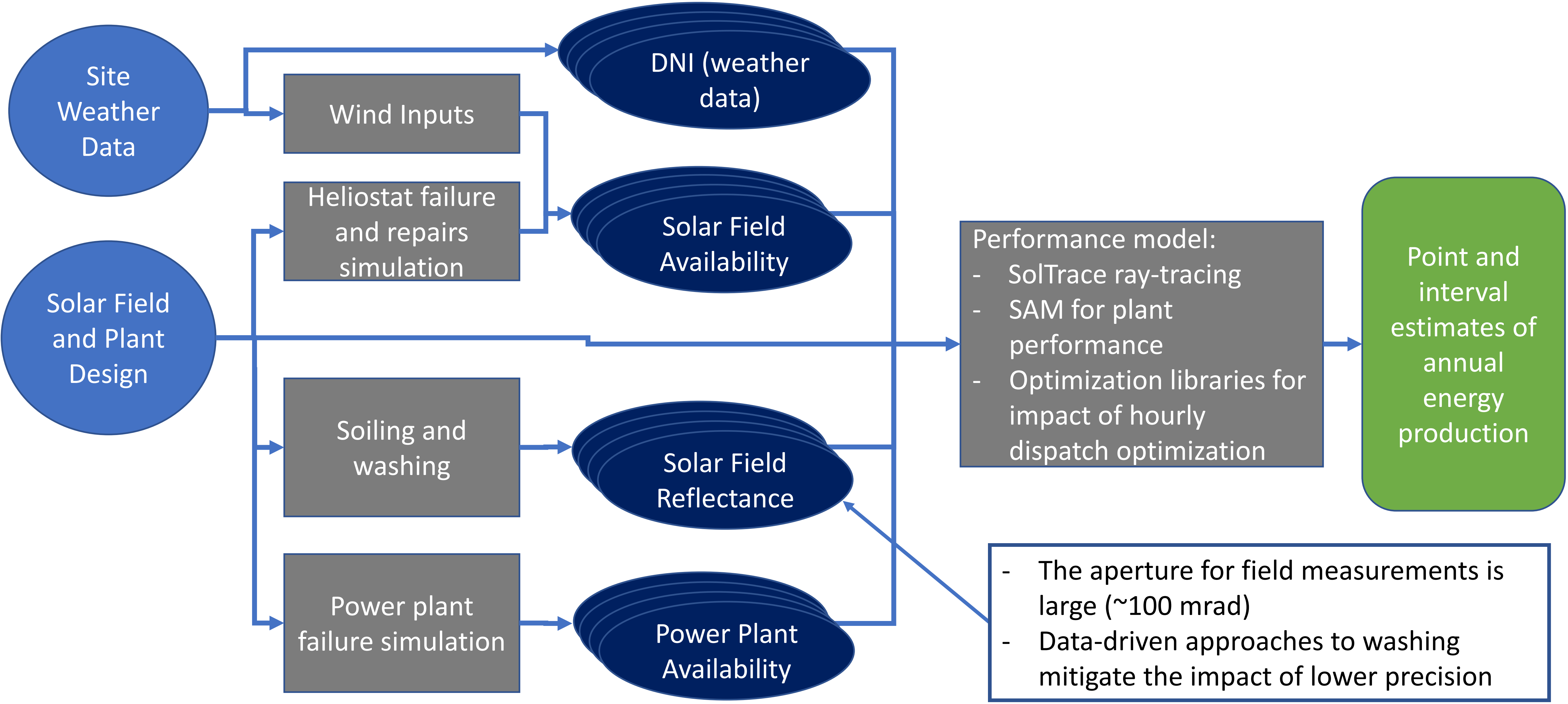
Broader Framework



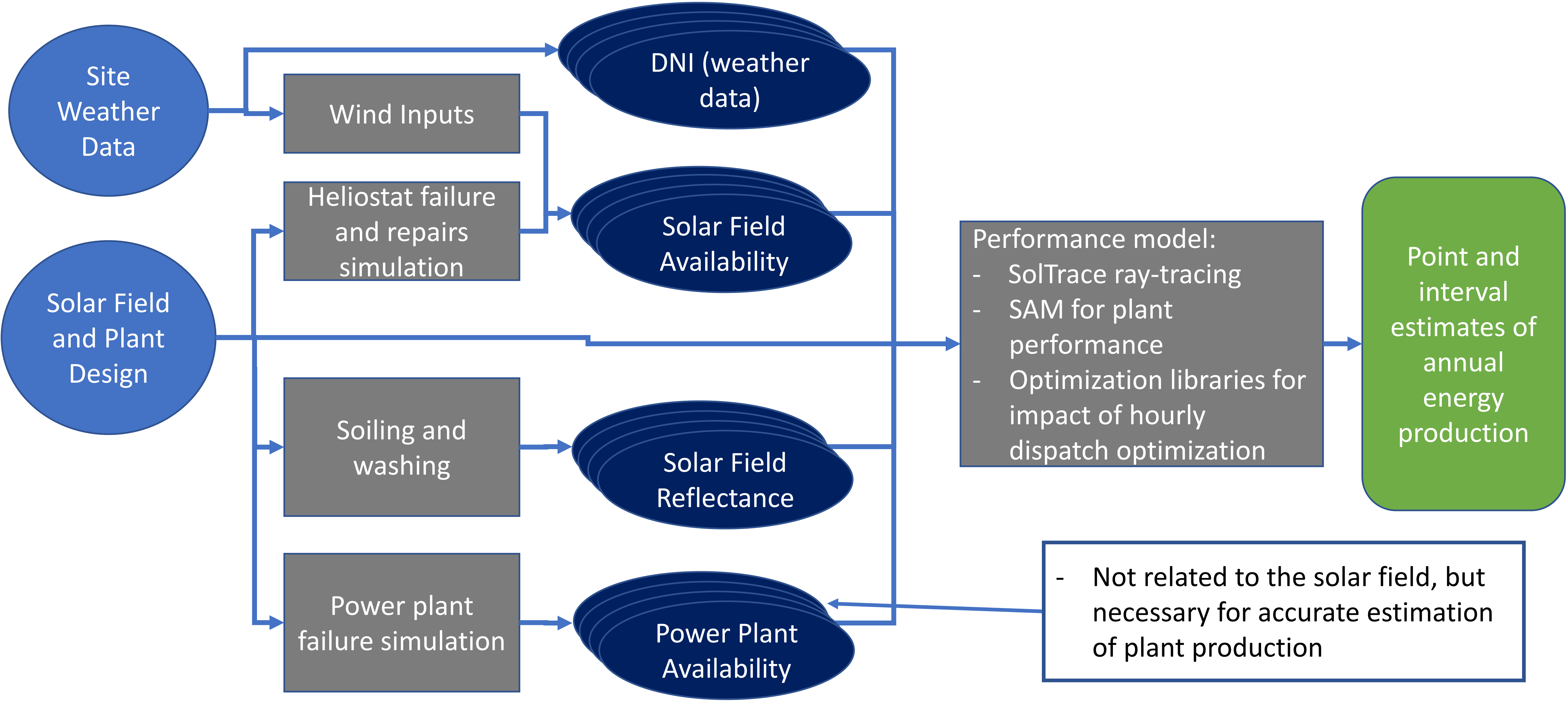
Broader Framework



Broader Framework



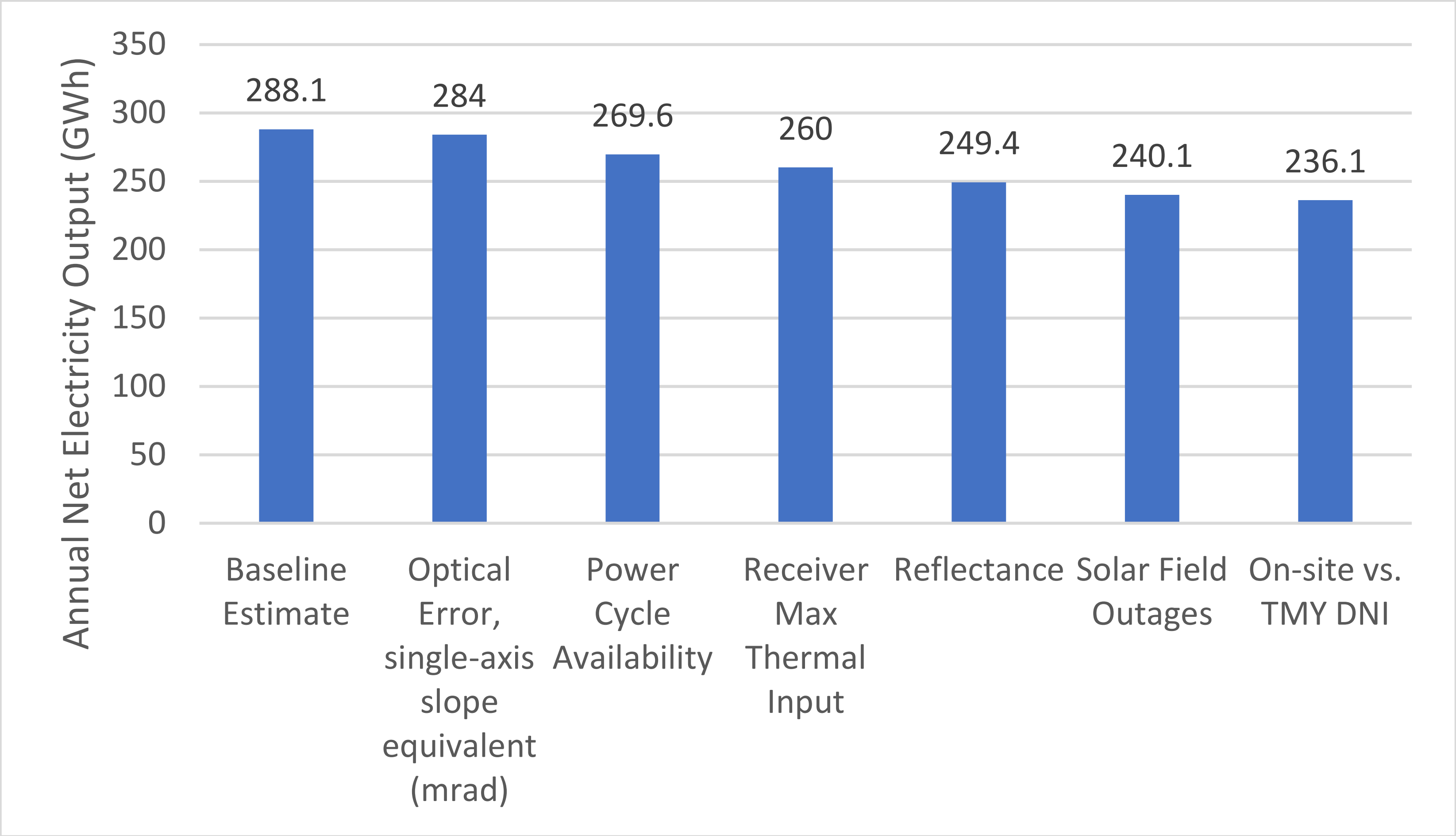
Broader Framework



Backcasting Exercise - Overview

- Starting with creating advertised results
  - Keep default modeling measures where applicable
  - Then, we make adjustments using what we know about the plant to obtain historical production levels
- We selected the Ivanpah Solar Generating Facility as our Case Study, which comes with caveats:
  - Our performance model assumes a different heat transfer system, but maintains the size of the solar field and (lack of) thermal energy storage
  - While our performance measure is annual electricity production, we intend to calibrate to monthly output in future work by incorporating more information on outage timing and duration
  - Future work will assess the differences between computationally expensive, but more precise, annual performance characterization in SolTrace and these estimates in SAM
- The inputs we adjust in our case study are informed by a site visit to understand operations

Our tuning to historical parameters can yield historical production



Actual 2019 production: 234.7 GWh (~1% lower)

Summary

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Moving forward

- HelioCon Year 2 backcasting and framework development:
  - Build out scripts connecting submodels and tools
  - Determine a parameter surface for key inputs that matches monthly output at Ivanpah
    - Sensitivity analysis of key inputs, model uncertainty
  - Take best guess at wind outages and “bad weather days” to match performance
- Out-year tool development:
  - Integrate existing DNI forecasting tools from literature, use tools and (30 years of) historical data to understand variation in year-to-year measured DNI (and measurement uncertainty)
  - Wind models:
    - Review wind data studies at >100 m, determine how useful the data at low elevation is
    - Compare Wind Toolkit data to hourly data and assess usefulness in performance prediction for outages on the ground
  - Integrate tools in a library to incorporate key uncertainty measures and simulate time-series performance forecasts

Thank you!

Questions?

alexander.zolan@nrel.gov

NREL/PR-5700-87045

This work was authored by the National Renewable Energy Laboratory, operated by Alliance for Sustainable Energy, LLC, for the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308. Funding provided by U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Solar Energy Technologies Office under award number 38896. The views expressed in the article do not necessarily represent the views of the DOE or the U.S. Government.