U.S. Department of Energy
HelioCon
Heliostat Consortium for Concentrating Solar-Thermal Power

A Performance Forecasting Framework for Concentrating Solar Power Systems

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

Existing Contributions

- 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

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.)

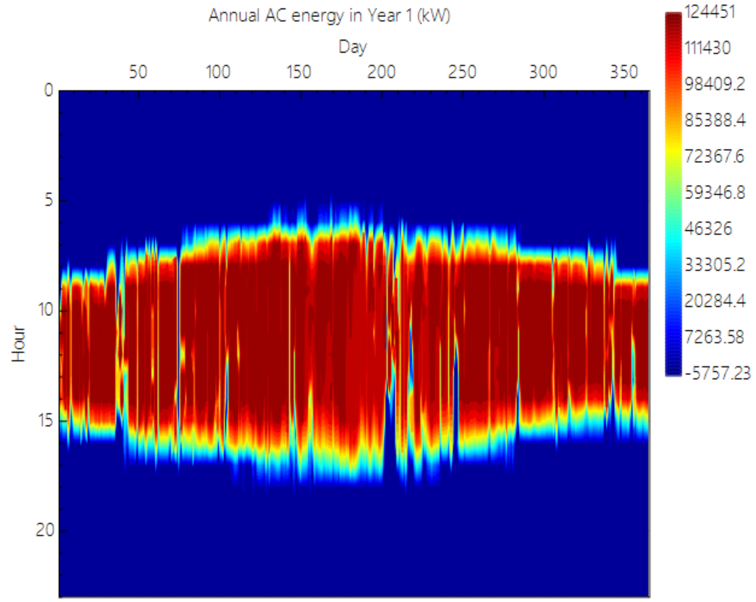
Solar Field Performance and Availability

- Reflectance in response to soiling, cleaning schedule
- Failures of individual heliostats and repairs

Central software tool: System Advisor Model

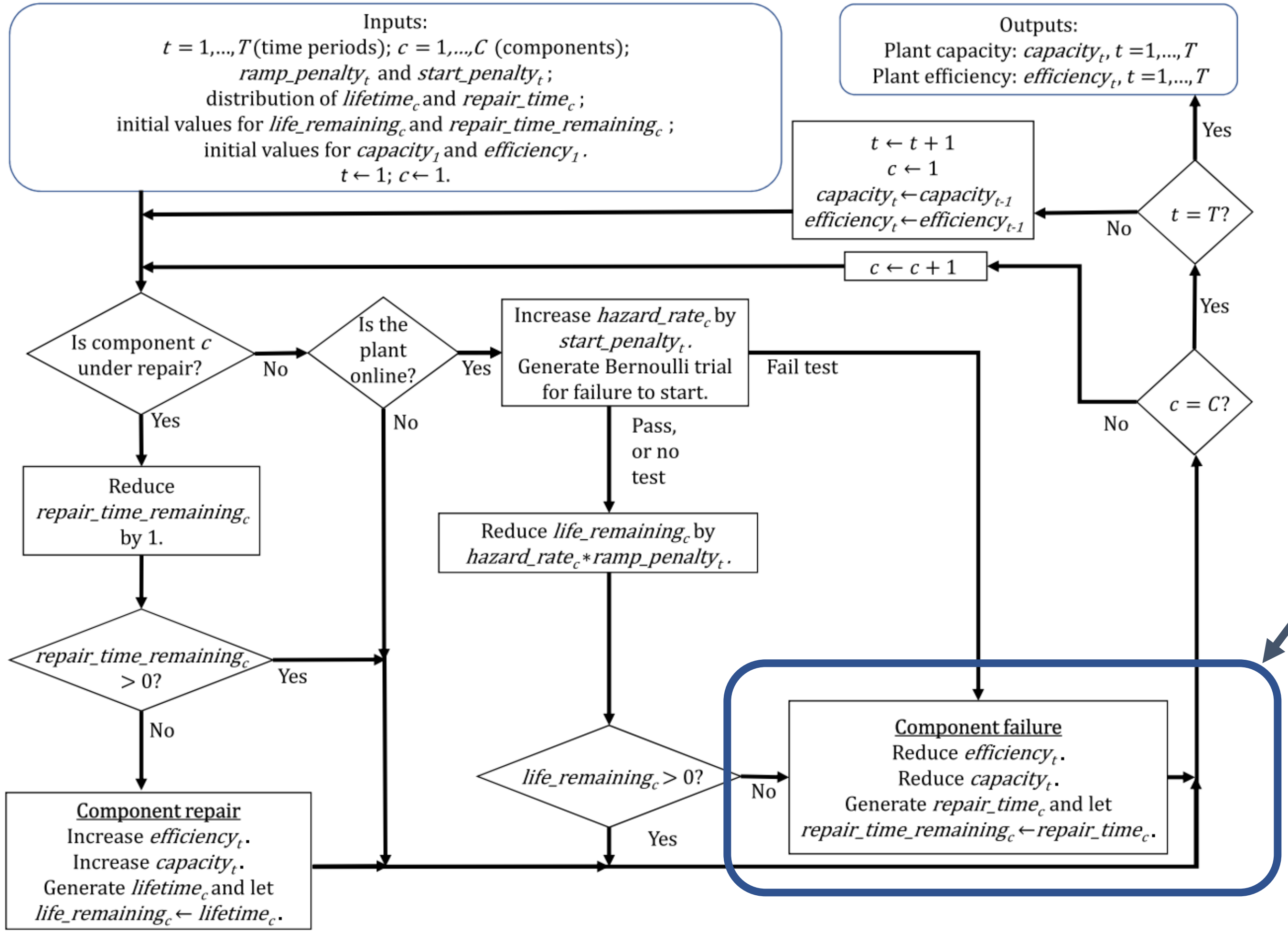
- Performance characterization model accepts time-series inputs for subsystem availability
  - Default is a constant multiplier for all hours in most cases
- We will use simulation sub-models for the time-series inputs, and build a confidence interval on system performance
- Includes plug-in for dispatch optimization

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

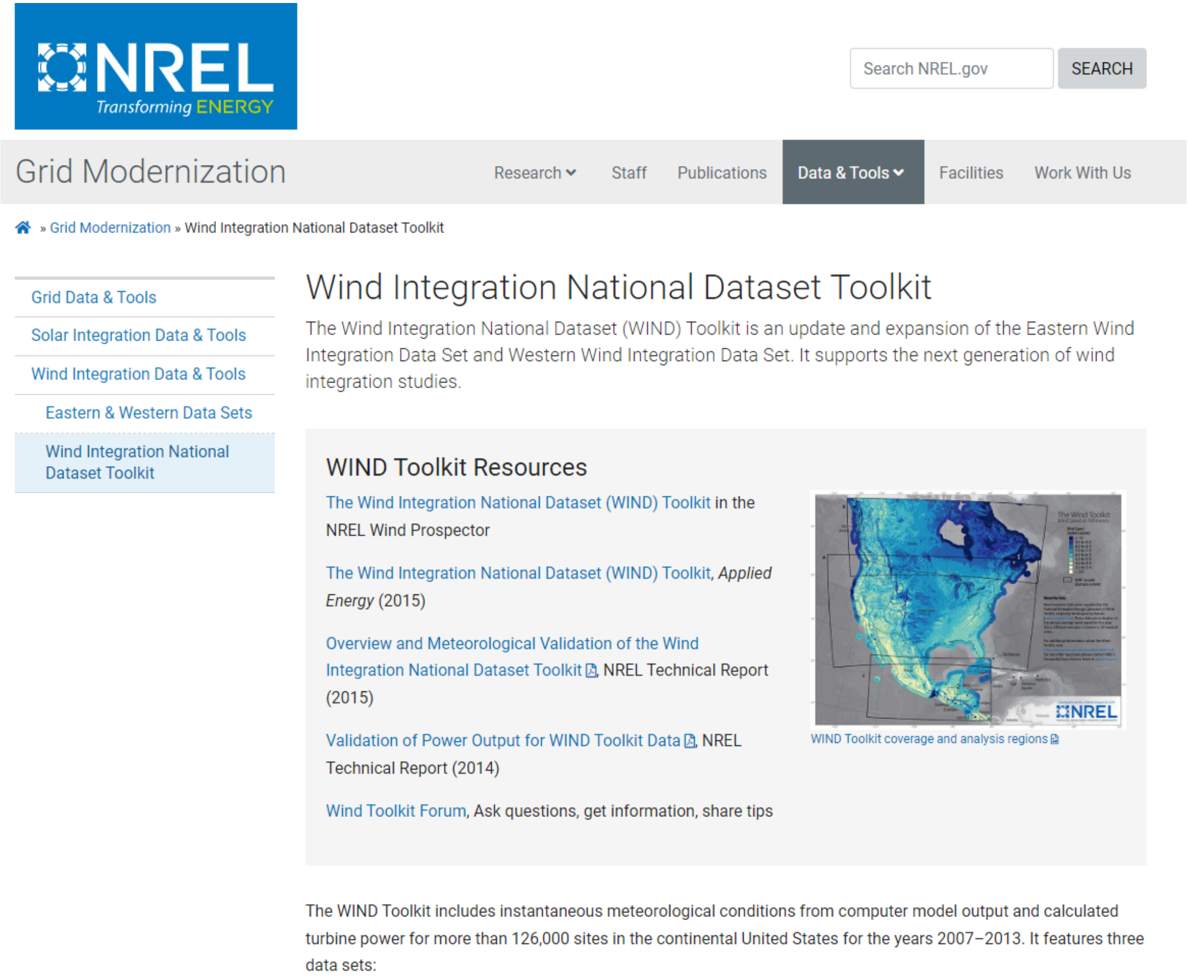


Component Failures can be caused by exceeding lifetime (running hours) or fail-to-start (Bernoulli) trials, using existing (nuclear) industry-provided distributions for component reliability

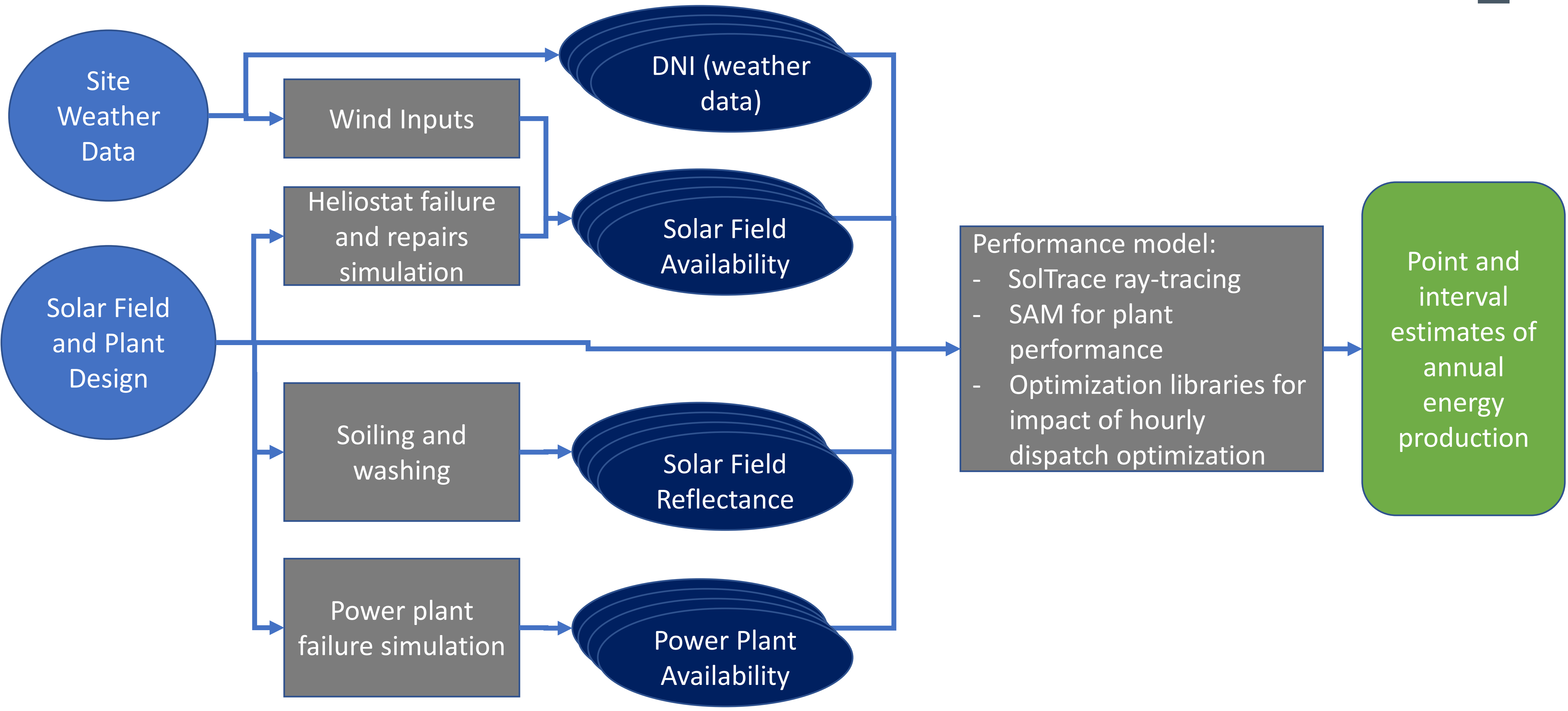
- Source paper: [Combining simulation and optimization to derive operating policies for a concentrating solar power plant | SpringerLink]

Solar field 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



Broader Framework



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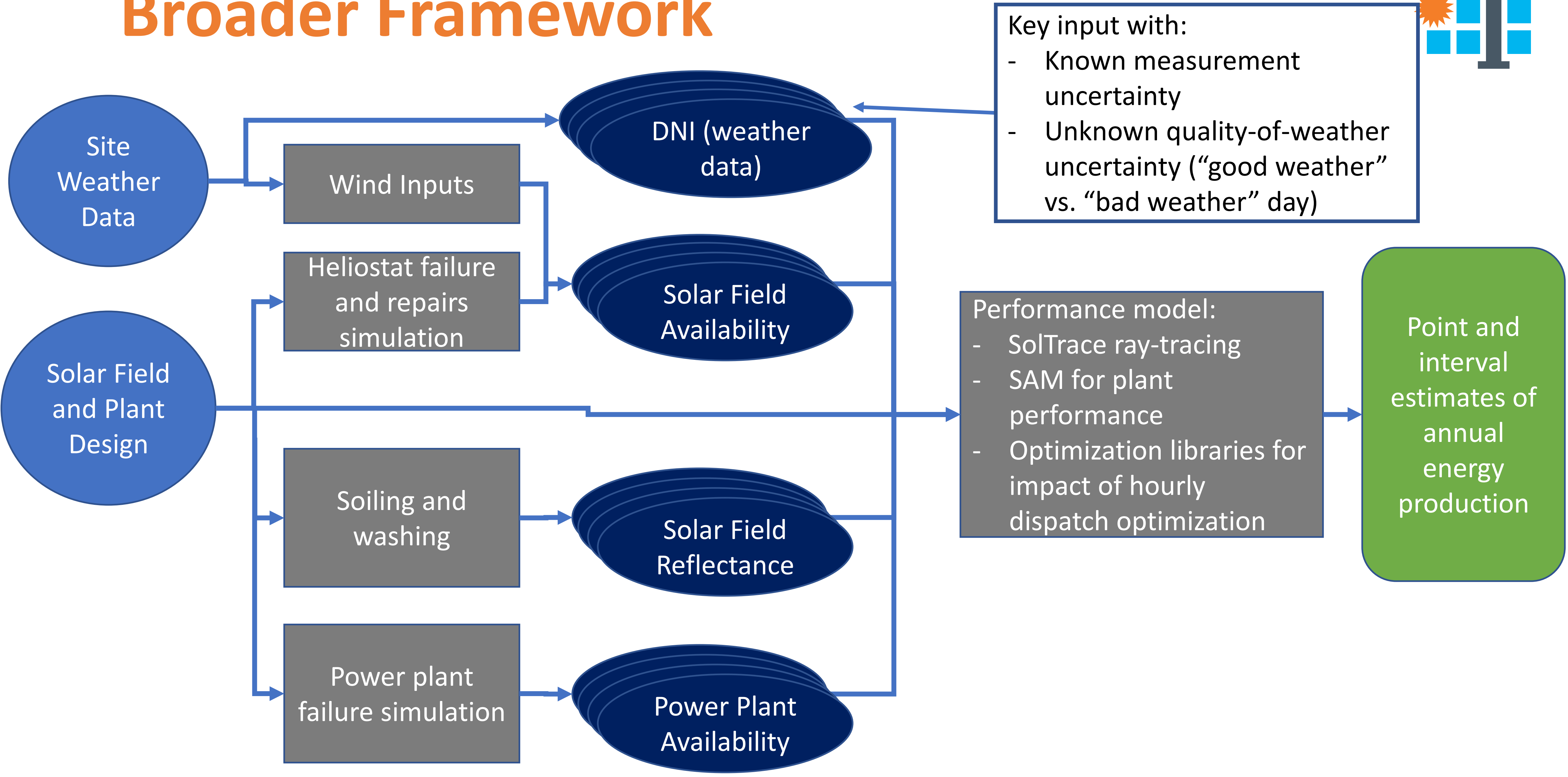
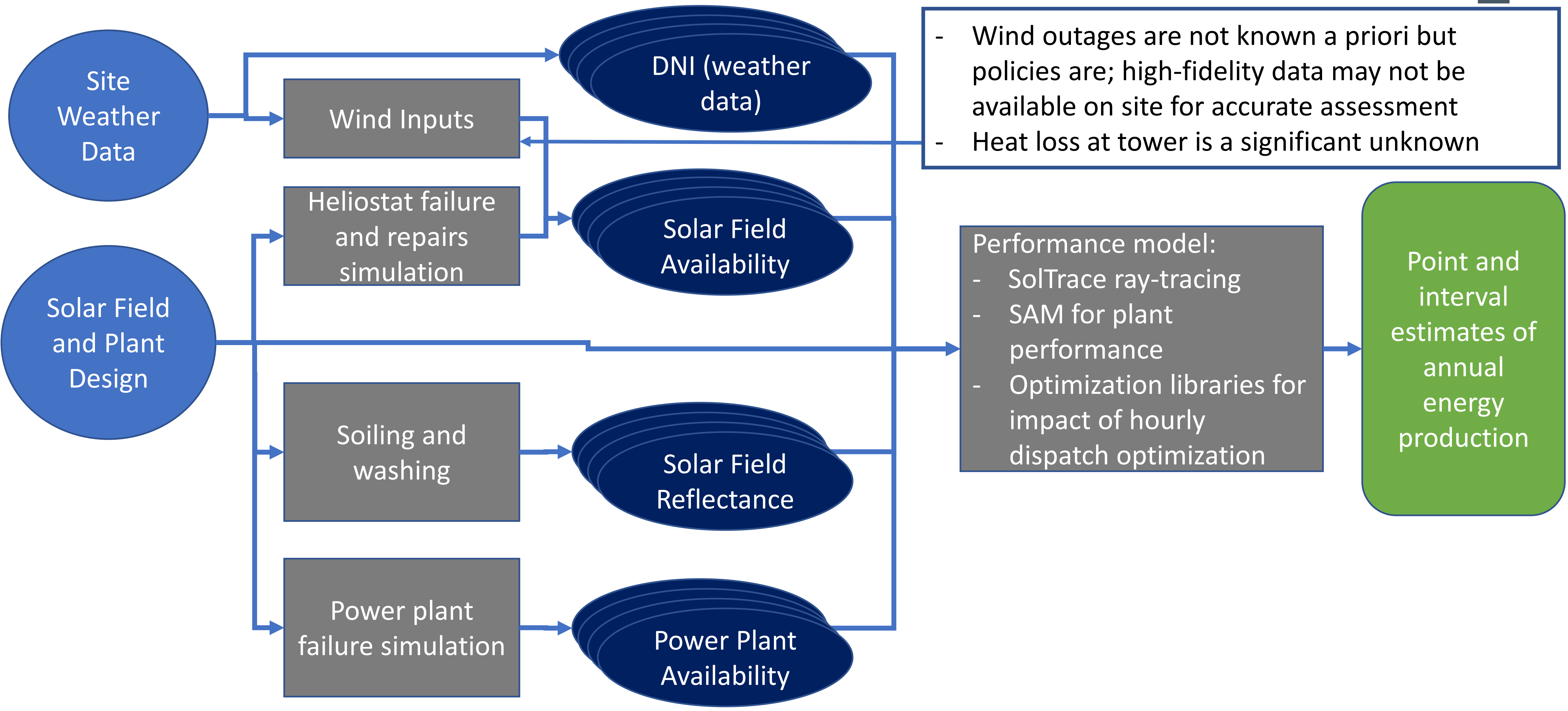
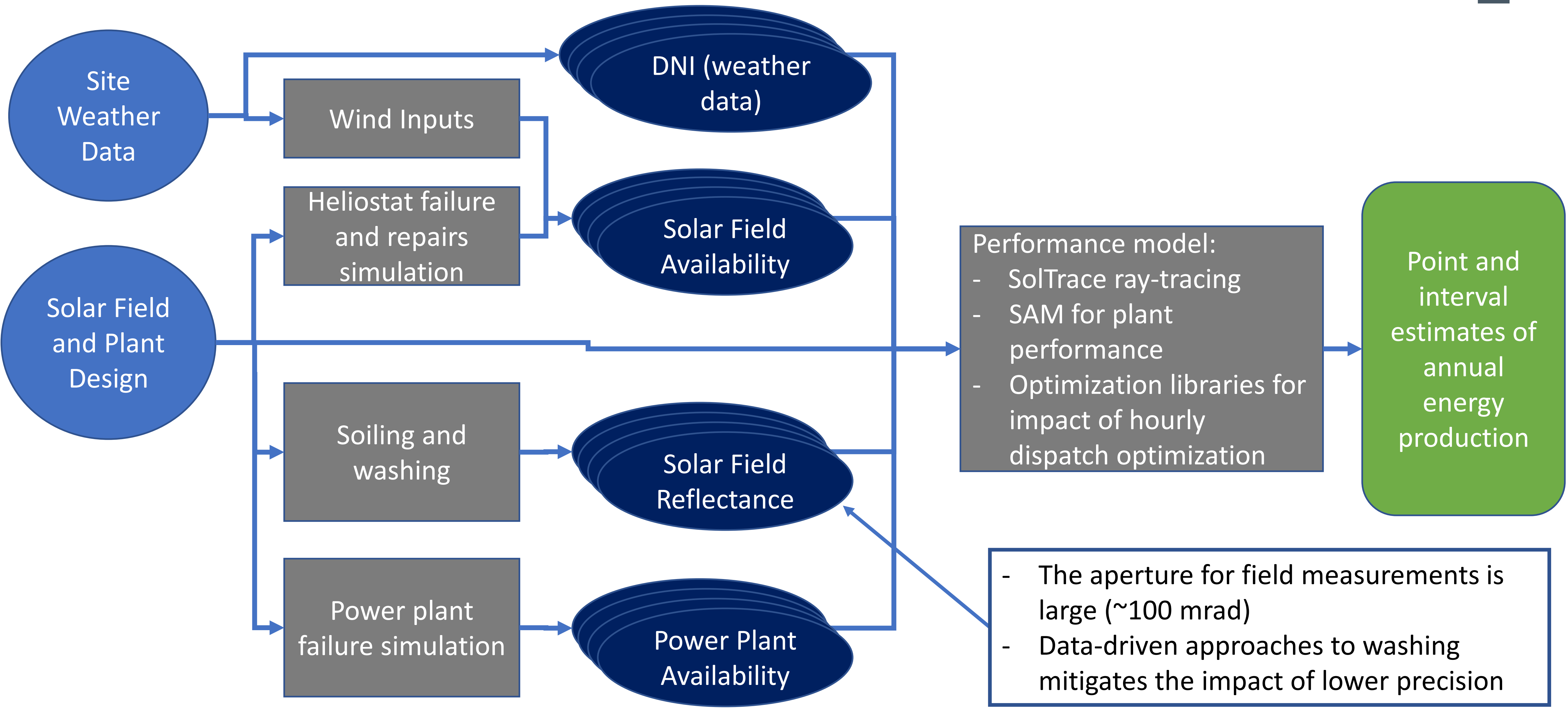


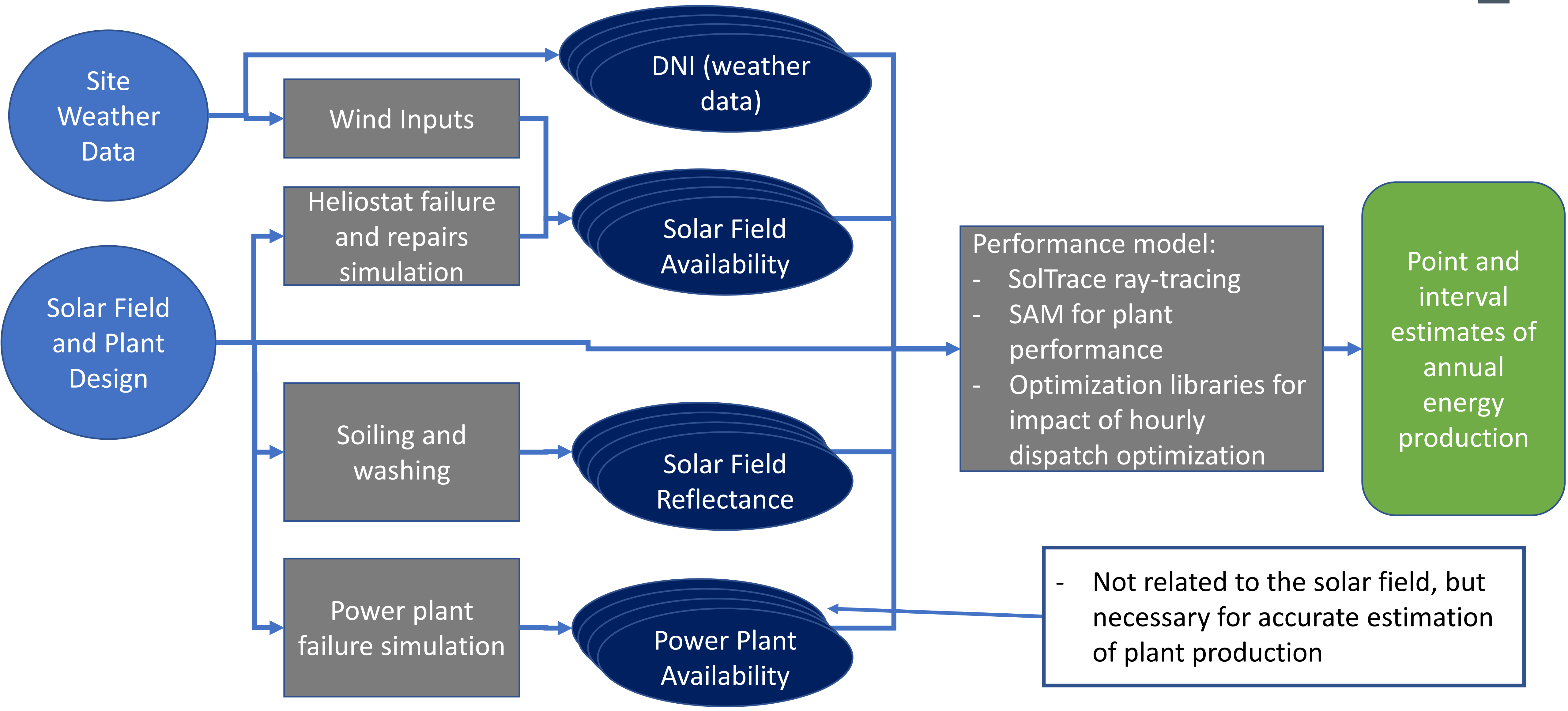
Broader Framework



Broader Framework



Broader Framework



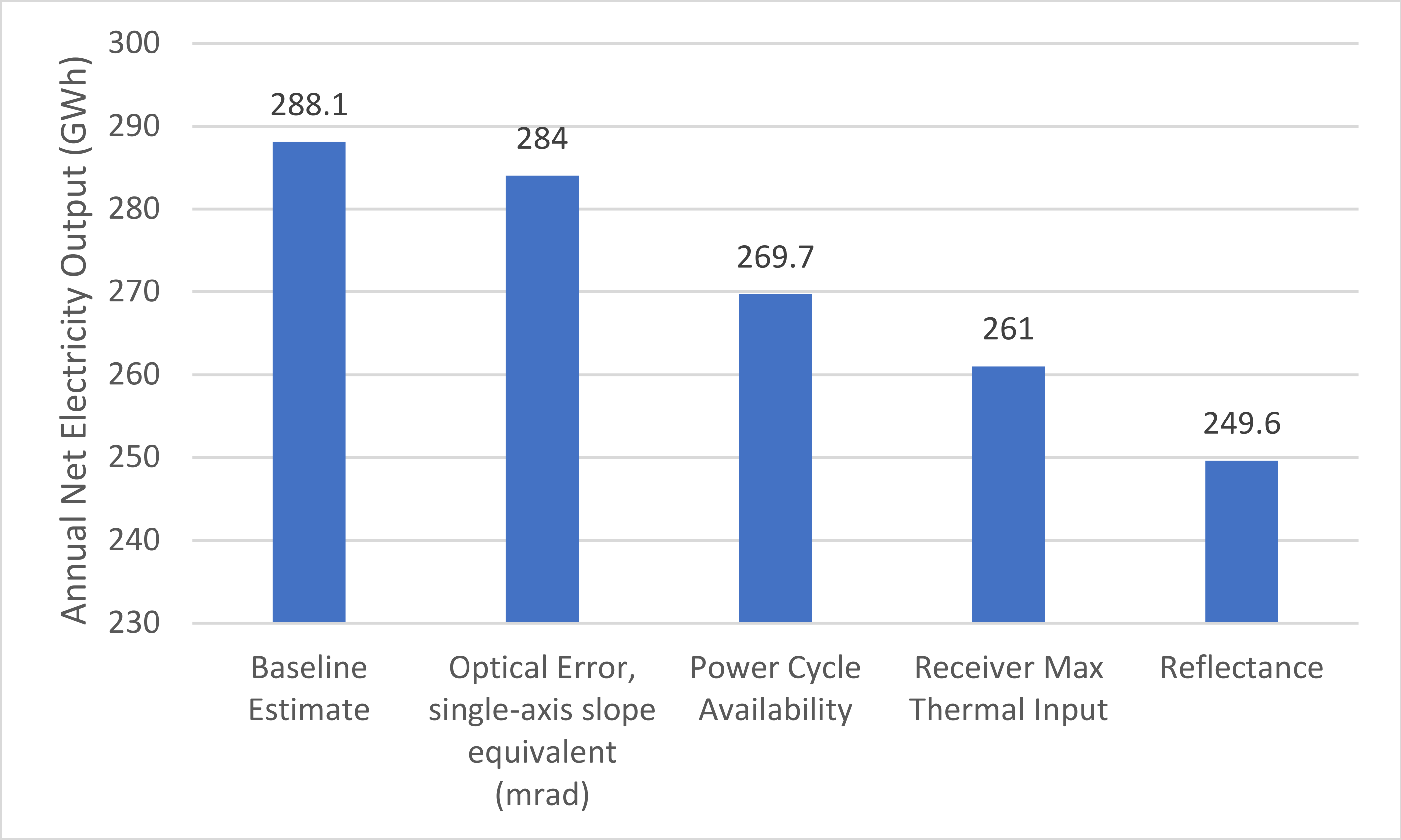
Backcasting Exercise - Overview

- Starting with creating advertised results
  - Keep default modeling measures where applicable
  - Then, we make adjustments using what we know about the plant (and about time series vs. constants) to obtain 2021 production
- 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

Backcasting Exercise – parameter adjustments

	Advertised	Actuals
Power Cycle Availability	96%	Simulated time series
Optical Error, single-axis slope equivalent (mrad)	1.53	2.00
Receiver Max Thermal Input	120%	100%
Heliostat Field Availability Loss	6%	8%
Reflectance	92%	86%
Weather	Representative Year	Historical Data
Heliostat Field Outages	Future Work	
Wind losses at receiver	Future Work	

More realistic parameter values increase estimate accuracy



Actual 2016 production: 244.5 GWh (~2% lower)

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?

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