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

Equivalent Breakeven Installed Cost

A Tradeoff-informed Measure for Technoeconomic Analysis of Candidate Heliostat Improvements

SolarPACES Conference 2022

Alex Zolan[1], Chad Augustine[1], Ken Armijo[2]

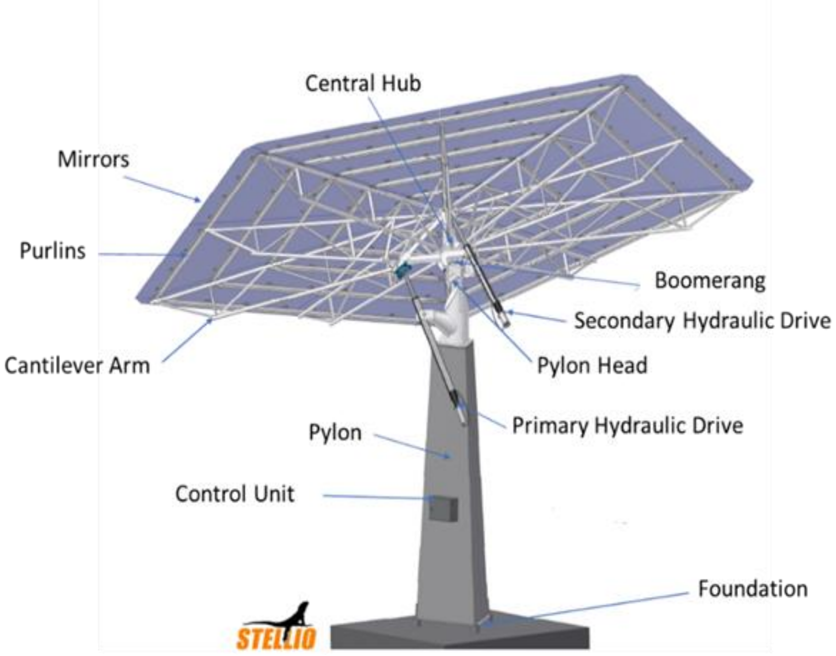
[1]National Renewable Energy Laboratory, Golden, CO, USA
[2]Sandia National Laboratories, Albuquerque, NM, USA

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

Agenda

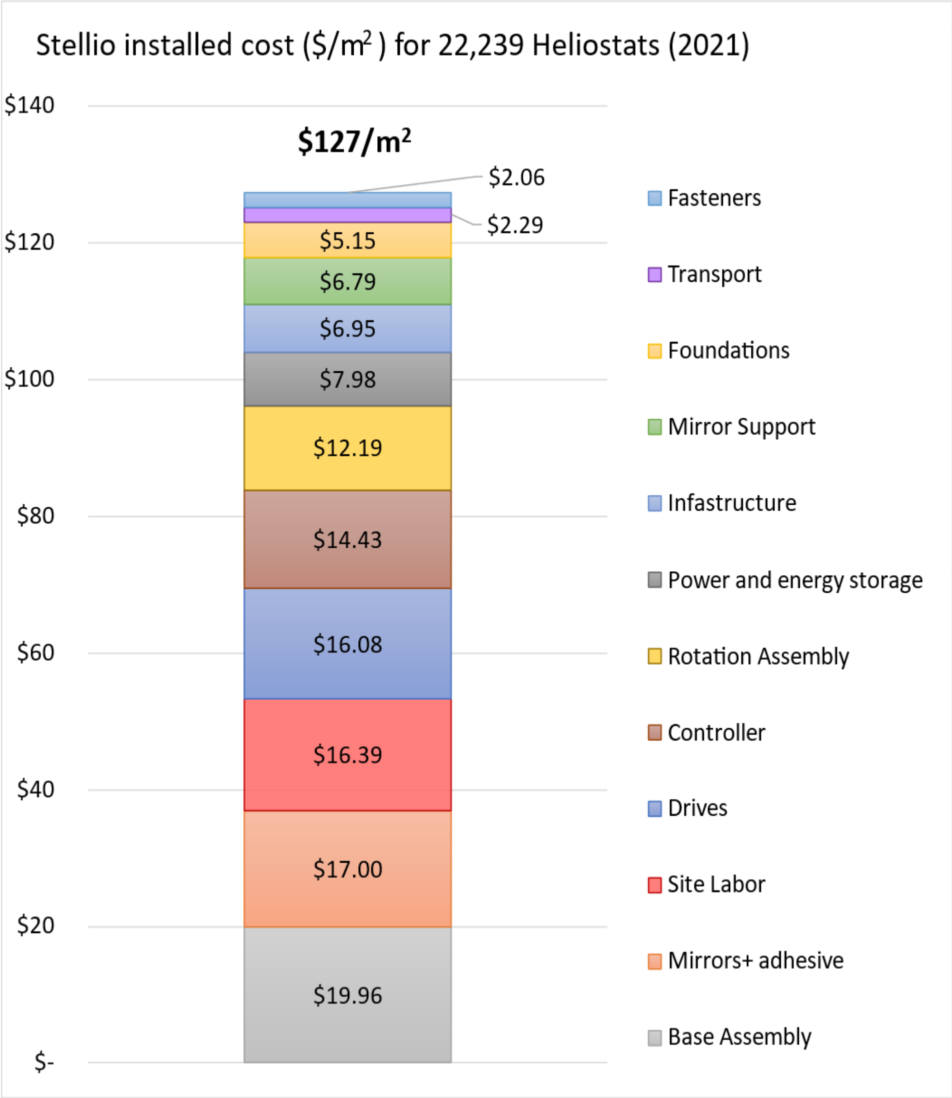
- Motivation
- Case Study Description
- Calculation of Metric
- Conclusions

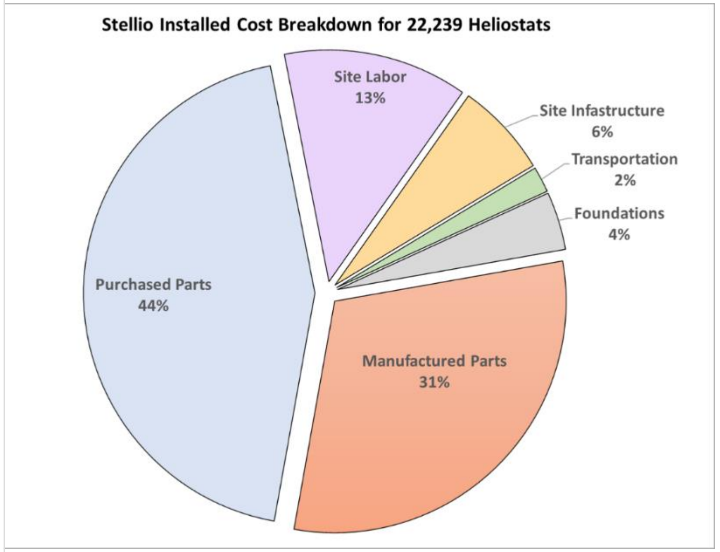
sbp Stellio Bottom-Up Analysis (Total: $127/m²)



Reflective area of ~48.5 m²

Assumed solar field with 22,239 heliostats represents 1,067,472 m² of total aperture area





~$127/m² installed cost (±10%)
- ~$7.5M assembly facility
- Base assembly (15.7%)
- Mirrors (13.4%)

Breakdown by category
- 44% purchased components (e.g., rivets, mirrors, drives)
- 31% manufactured parts (e.g., arms, frame…)

Source: Kurup et al., 2022, NREL/TR-7A40-80482

Motivation: What is a heliostat performance improvement worth?

- Technoeconomic analysis is useful for assessing the viability of technology updates
- Levelized cost of electricity (LCOE) and levelized cost of heat (LCOH) are useful measures of impact to total plant-life costs but offer limited perspective for incremental technologies
- We present a measure that recasts levelized costs as an equivalent budget for technology improvements
- The case study we present a heliostat's installed cost

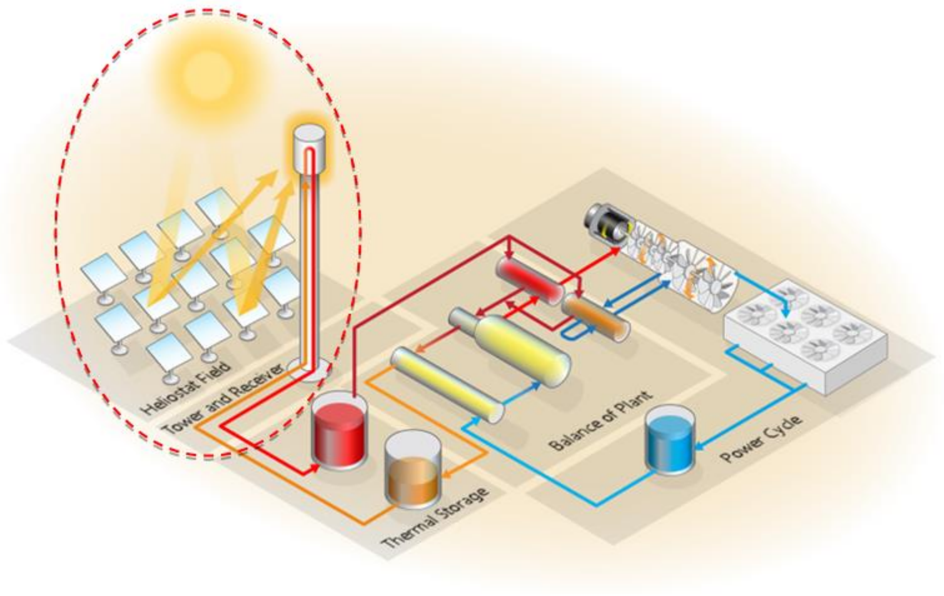
Heliostats in Ivanpah Solar Field, Unit 1

Metric calculation: LCOH

We choose LCOH as our chosen measure using the following metric to focus on the collection system and remove thermal energy storage and power cycle costs:

$$LCOH = LCOE \cdot \frac{Electrical\ energy\ produced}{Thermal\ energy\ delivered\ to\ the\ receiver} \cdot \frac{Capital\ cost\ of\ receiver\ and\ solar\ field}{Capital\ cost\ of\ plant}$$

We assume operating expenses are proportional to the capital costs of each subsystem in the plant



Scope of the CSP considered in our case study and metric[1]

[1]Image source: [Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power (Technical Report) | OSTI.GOV]

Case study details

Use case: single, central external receiver to supply thermal energy to an electric power plant, modeled in System Advisor Model (SAM)[1]

- We employ the baseline study from the HelioCon Roadmap Report[2] as a starting point (Location: Daggett, CA)
  - Net power output: 100 MWe
  - Surround heliostat field
    - Solar multiple: 2.7
  - External receiver
    - Solar salt (60% $NaNO_3$/40% KNO_3)
      - Max heat flux – 1 MW/m^2
    - Hot side temp: 575°C
    - Cold side temp: 290°C

Key Cost and Performance Details:

1. Installation cost:
   a. $50/$m^2$ (SunShot 2030 target)
   b. $140/$m^2$ (Baseline case from Roadmap Report)
2. Optical error: 2.0 mrad
3. Reflectance (includes soiling): 90%
4. Full-plant O&M cost: $66/kW-year
5. Availability: 94%
6. Construction time: 24 months

[1] https://sam.nrel.gov
[2] Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power (Technical Report) | OSTI.GOV

Parametric study details

We vary the following parameters by +/- 50%:

- Optical error (single-axis slope equivalent)
- Heliostat installed cost
- Reflectance loss vs. ideal image
- Fixed annual, plant-wide O&M cost

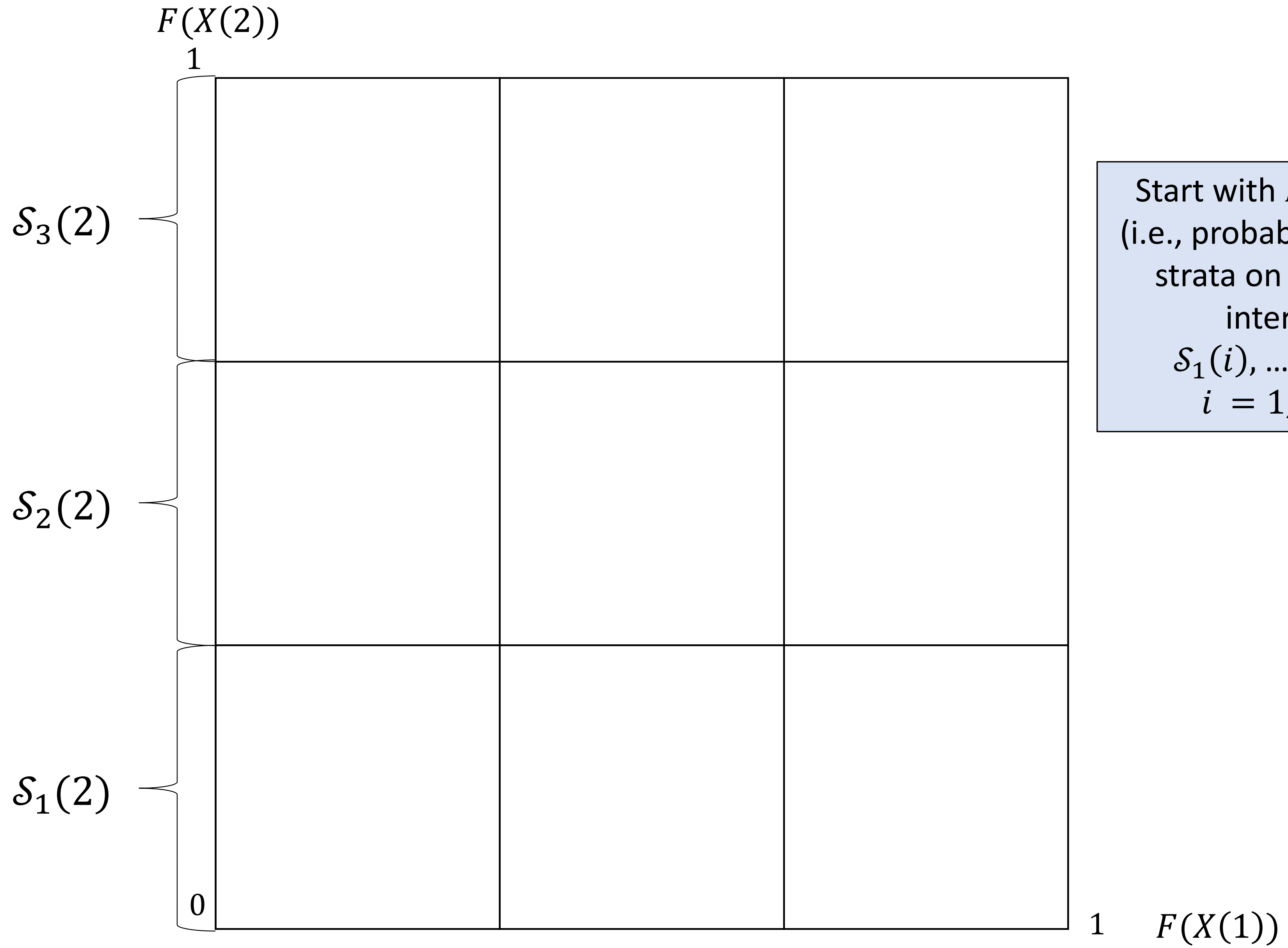
We vary one parameter at a time to start, and we allow a new design to be chosen in each instance

[1] https://sam.nrel.gov
[2] Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power (Technical Report) | OSTI.GOV

Solution exploration method: Latin hypercube

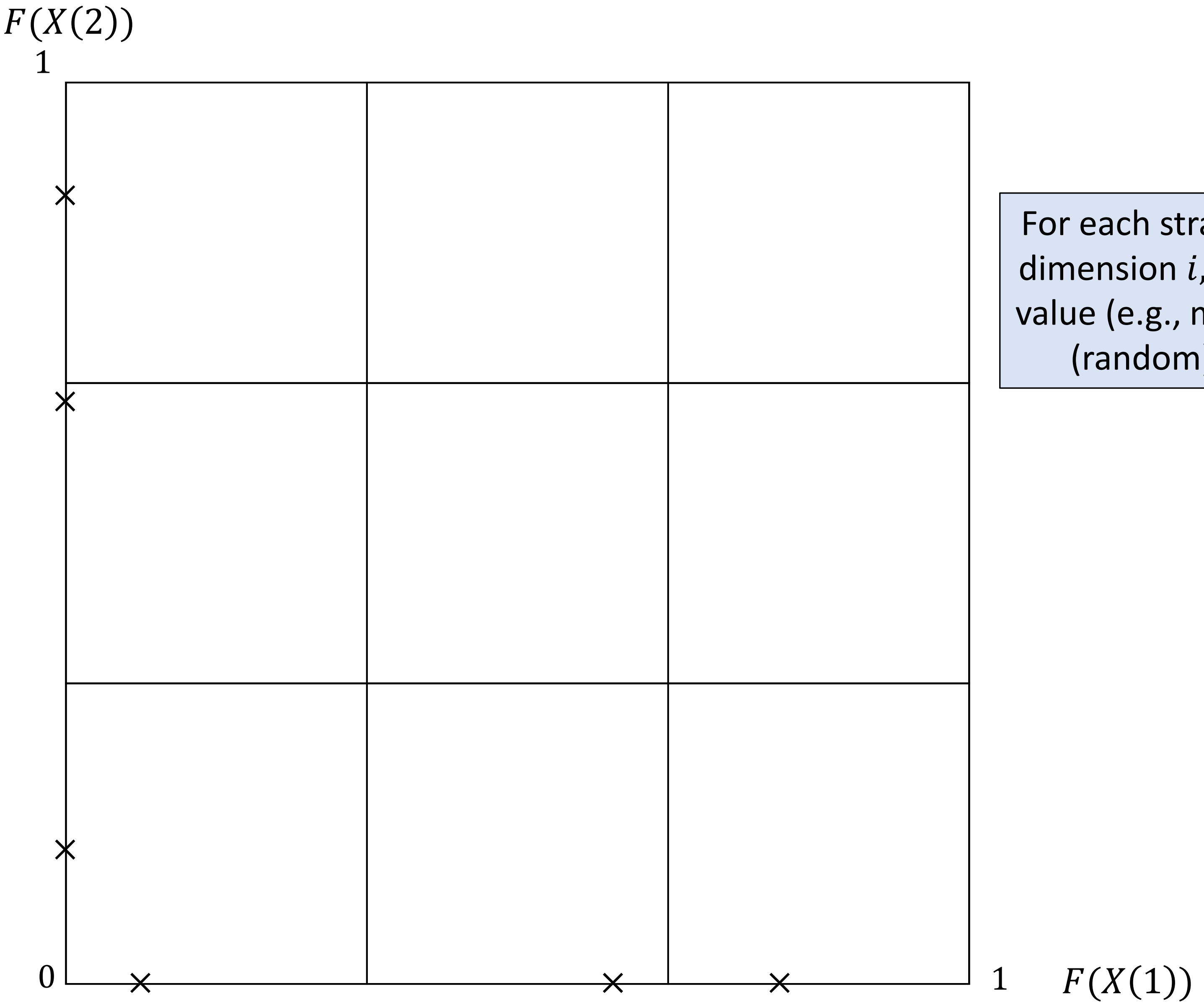
- The optimization model in SAM includes parameter exploration, but good starting points are required to avoid local minima
- Our approach develops a Latin hypercube of designs to ensure sufficient exploration of the parameter space
- We vary the following parameters:
  - Design-point DNI (adjusts target number of heliostats in field, can simulate oversizing or undersizing)
  - Tower height
  - Receiver height (we assume diameter is proportional to height)
- Note: SolarPILOT generates the solar field for each case, using the above parameters as input

2-dimensional Latin hypercube example (n=3)



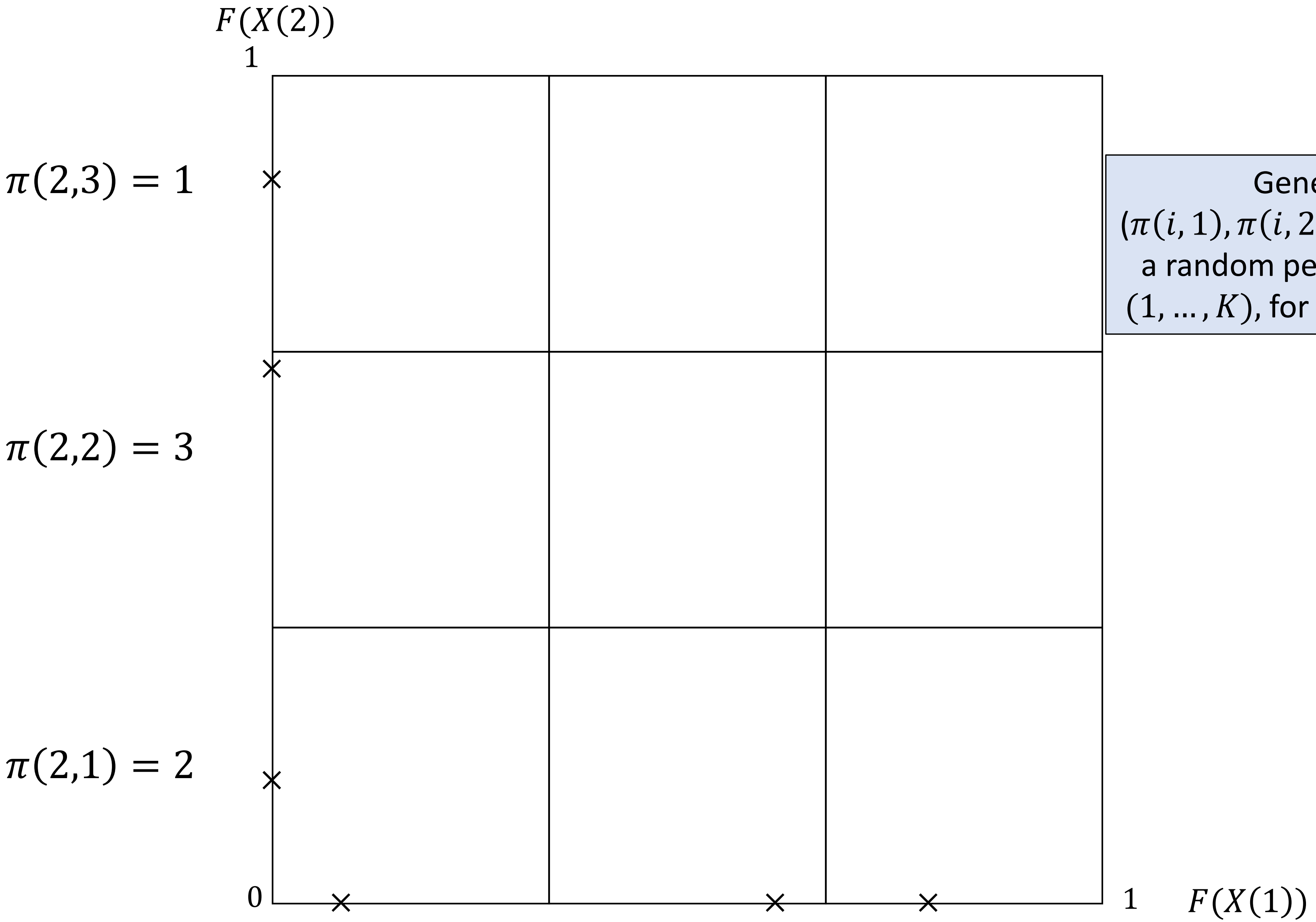
Start with K uniform (i.e., probability-equal) strata on the [0,1] interval, $\mathcal{S}_1(i), \ldots, \mathcal{S}_K(i)$, $i = 1, \ldots, d$

2-dimensional Latin hypercube example (n=3)



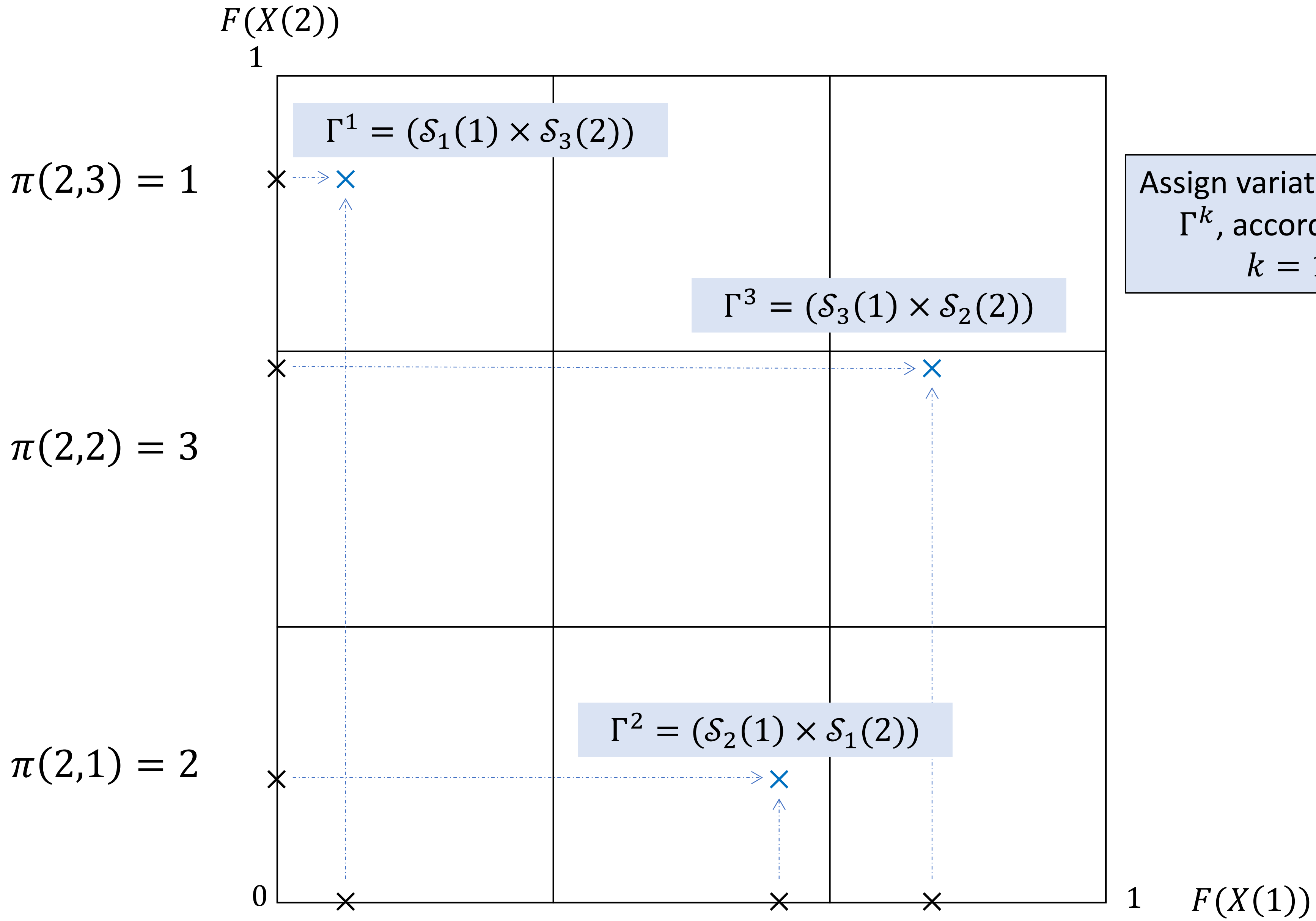
For each stratum k and dimension i, generate a value (e.g., midpoint) or (random) variate

2-dimensional Latin hypercube example (n=3)



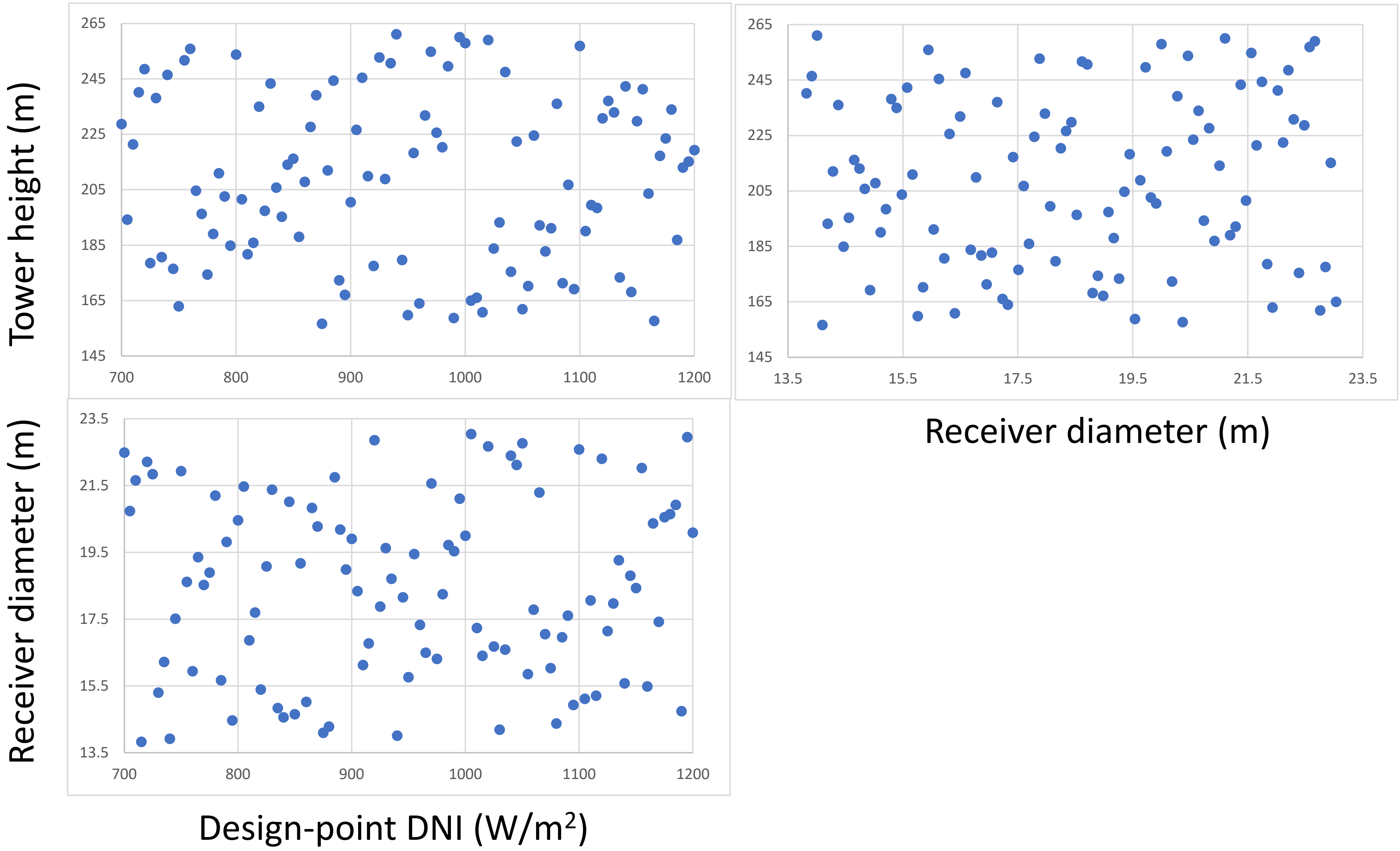
Generate $(\pi(i,1), \pi(i,2), \ldots, \pi(i,K))$, a random permutation of $(1, \ldots, K)$, for all $i = 2, \ldots, d$

2-dimensional Latin hypercube example (n=3)



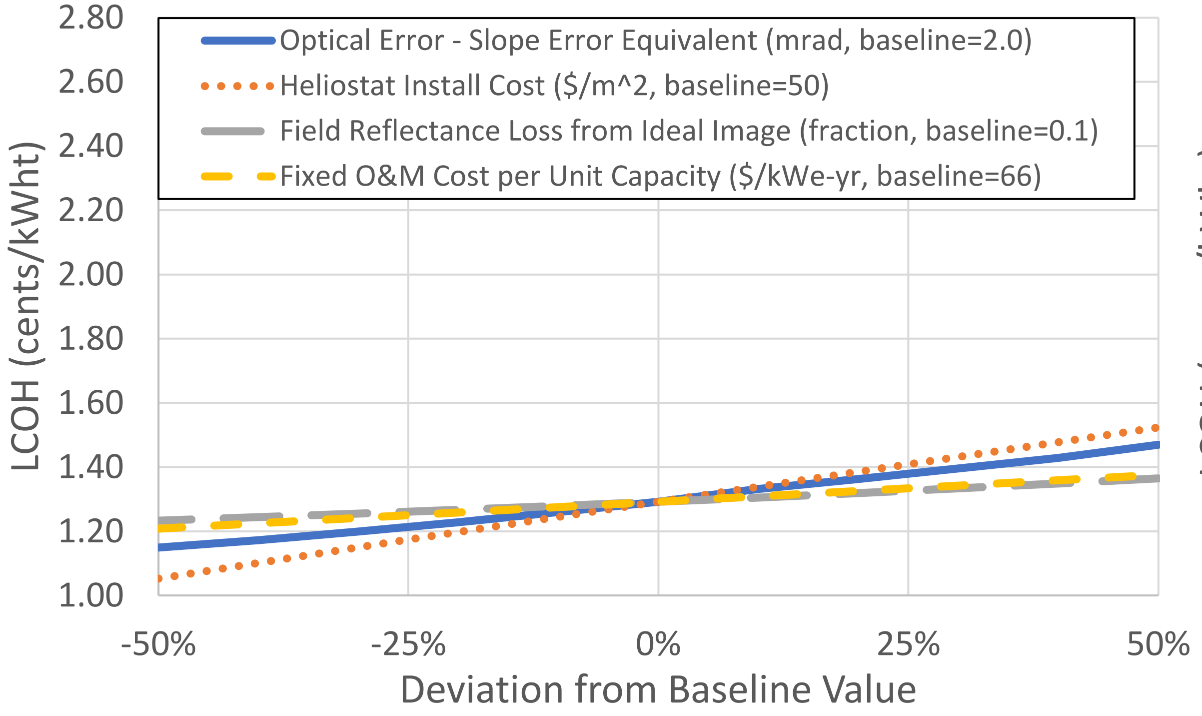
Assign variates to LHS cells, Γ^k, according to $\pi(\cdot)$, $k = 1, \ldots, K$

Solutions generated via Latin hypercube (n=101)

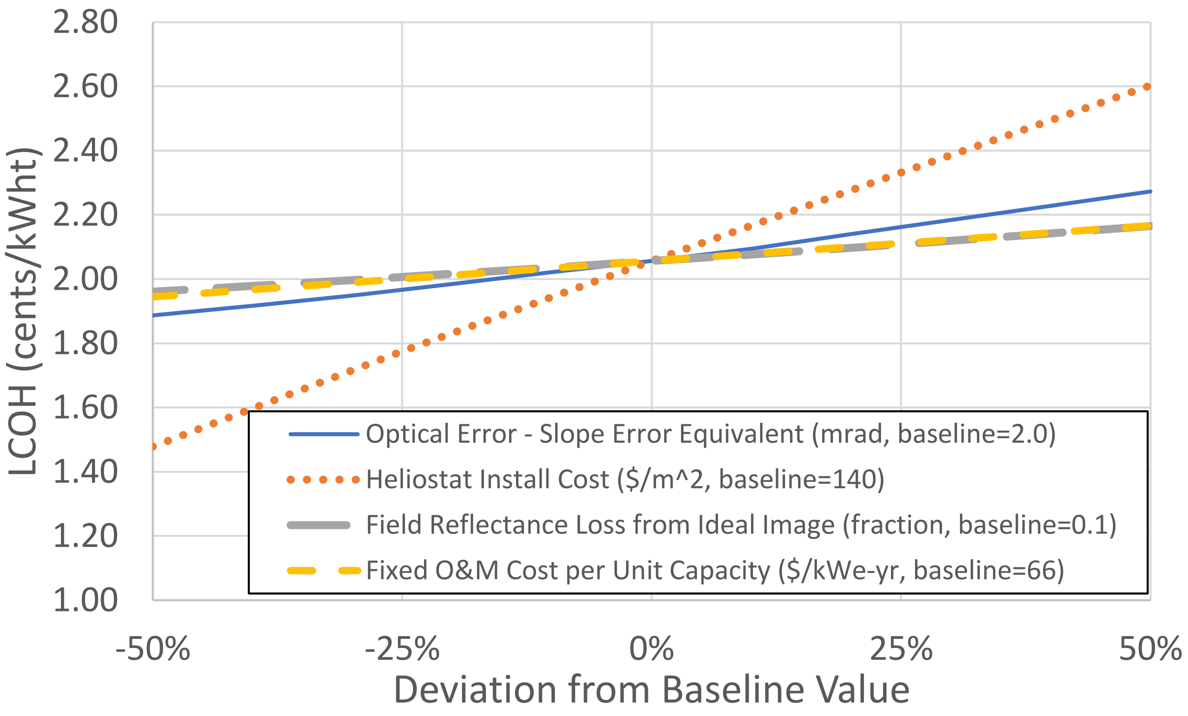


Parametric results: LCOH summary, \$50/m² and \$140/m² scenarios

$50/m² case



$140/m² case



- O&M cost and reflectance losses exhibit a near-1:1 tradeoff regardless of the baseline installed cost
- LCOH is less sensitive to relative changes in capital cost for the \$50/m² case

Recasting LCOH as Equivalent breakeven installed cost (EBIC): Motivation

- HelioCon is focused on the heliostat's cost and performance
- Changes to heliostat performance parameters do not happen in a vacuum
  - Cost reductions are likely to impact performance
  - Conversely, performance improvements come with a change in cost
  - EBIC clearly shows this tradeoff in an easy-to-read metric
- EBIC can help set targets or budgets for prospective technology changes, and can help with decision-making or prioritization of future R&D

Metric calculation: EBIC

Obtain LCOH (L) as an affine function of capital cost (C) via linear regression to get terms a and b:

$$L = a \cdot C + b$$

The equivalent installed cost (C') uses the **new** LCOH (L') and the **baseline** installed cost (C) and LCOH (L):

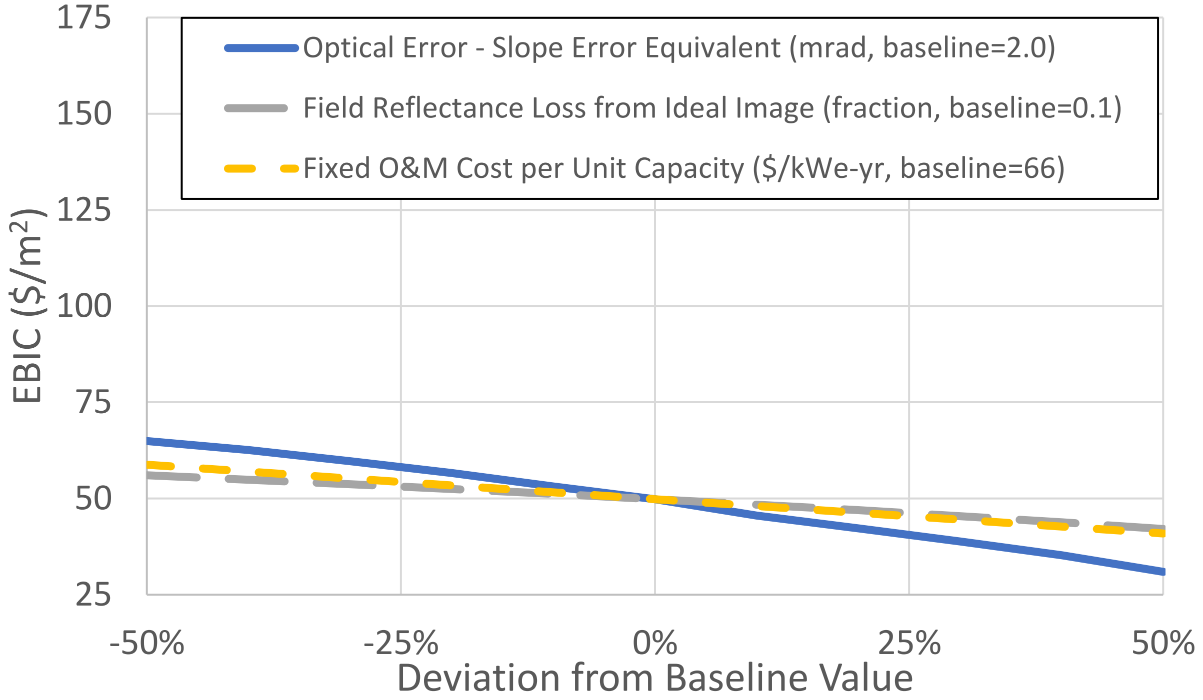
$$C' = \frac{(L' - L)}{a} + C$$

The EBIC obtains the same LCOH as the baseline case under the new conditions:

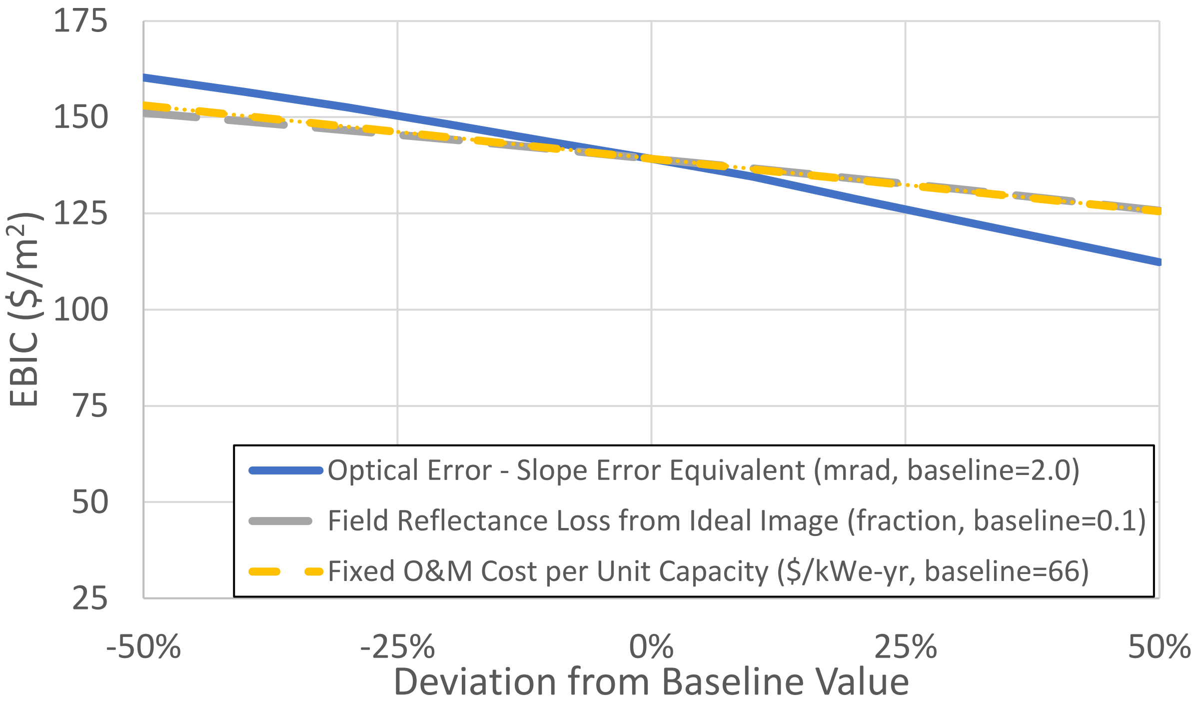
$$C^* = 2 \cdot C - C'$$

Results: EBIC summary, $\$50/m^2$ and $\$140/m^2$ scenarios

$\$50/m^2$ case

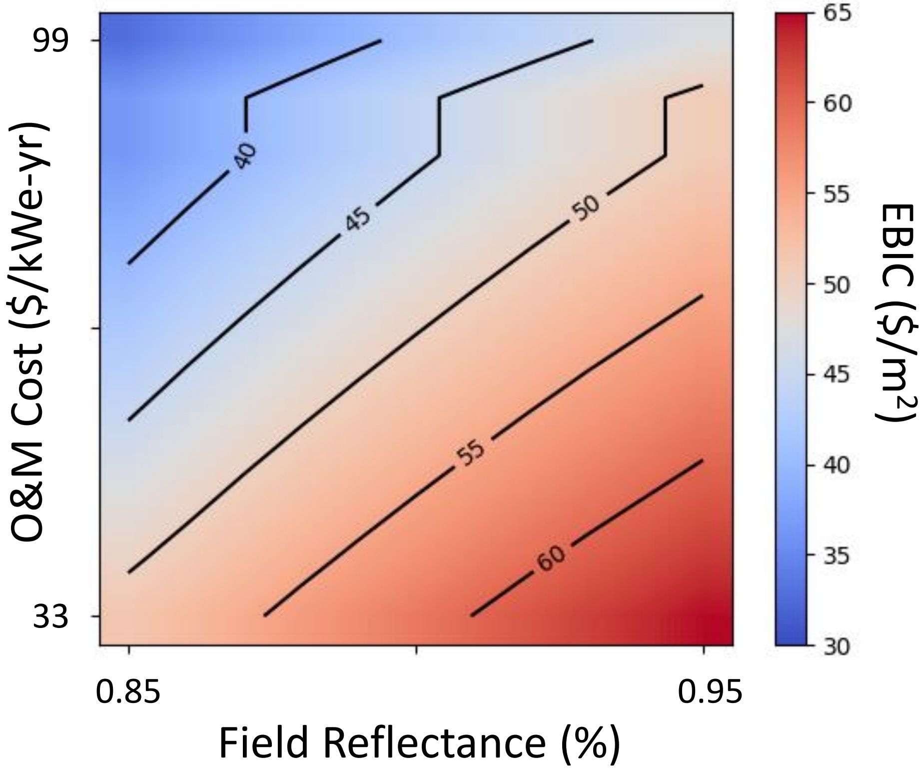


$\$140/m^2$ case



- For the $\$140/m^2$ case, a heliostat with a 25% reduction (improvement) in optical error can sustain the same LCOH if the change only increases installed heliostat costs by $\$10/m^2$.
  - If it costs more than this to improve heliostat optics, the benefits are outweighed by the heliostat installed cost increase

Results: Heatmap of EBIC



- Nearly diagonal lines confirm the approximately 1:1 tradeoff between relative O&M costs and field reflectance losses for a wider range of starting points
- Overall impact to EBIC for these measures is limited, indicating performance improvement might offset, but cannot replace, installation cost reductions to obtain the $50/m^2 goal from current costs

Summary

- Develop a novel TEA metric that can provide budgetary guidance on candidate heliostat improvements
- Demonstrate the usefulness of the metric via a case study using candidate heliostat performance improvements and cost measures
- Key insight: it will be difficult for performance improvements to meet the SunShot 2030 goal of $50/m^2$ installed cost alone but they can be a contributor to driving down effective heliostat costs

Thank you!

Contact: alexander.zolan@nrel.gov

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