Equivalent Breakeven Installed Cost: A Tradeoff-informed Measure for Technoeconomic Analysis of Candidate Heliostat Improvements

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Alex Zolan¹, Chad Augustine¹, Ken Armijo²

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

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

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

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**Key Cost and Performance Details:**
1. Installation cost:
   - $50/m\(^2\) (SunShot 2030 target)
   - $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

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\(^1\)https://sam.nrel.gov

\(^2\)Roadmap to Advance Heliostat Technologies for Concentrating Solar-Thermal Power (Technical Report) | OSTI.GOV
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.
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.
Start with $K$ uniform (i.e., probability-equal) strata on the $[0,1]$ interval, $S_1(i), \ldots, S_K(i)$, $i = 1, \ldots, d$.
For each stratum $k$ and dimension $i$, generate a value (e.g., midpoint) or (random) variate.

2-dimensional Latin hypercube example (n=3)
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\[ F(X(2)) \]

\[ \pi(2,3) = 1 \]
\[ \pi(2,2) = 3 \]
\[ \pi(2,1) = 2 \]

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, \( \Gamma^k \), according to \( \pi(\cdot) \),

\[ k = 1, \ldots, K \]

\[ \Gamma^1 = (S_1(1) \times S_3(2)) \]

\[ \Gamma^2 = (S_2(1) \times S_1(2)) \]

\[ \Gamma^3 = (S_3(1) \times S_2(2)) \]
Solutions generated via Latin hypercube (n=101)
Parametric results: LCOH summary, $50/m^2$ and $140/m^2$ scenarios

- 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 $50/m^2$ 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

- 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/m² 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