Federal Ministry for Economic Affairs and Climate Action

Heliodor (0324310)

# HELIOSTAT FIELD PERFORMANCE TESTING GUIDELINE

– A Step Forward in the Measurement of Distributed Concentrator Systems

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1 German Aerospace Center (DLR), Institute of Solar Research, Spain/Germany
2 Kraftanlagen Energies & Services GmbH, Germany
3 CSP Services GmbH, Germany
4 sbp sonne GmbH, Germany
5 previously sbp sonne GmbH, now Glasspoint Technology Center GmbH
6 Synhelion, Germany

DLR

# Preface

available

**Heliostat Performance Testing Guideline**

- for single heliostat evaluation
- focused on prototype validation & qualification

DLR, Heliostat Testing Platform with Stellio

**Heliostat Field Acceptance Guideline**

- for whole heliostat fields
- focused on the performance measurement of an industrial-sized field

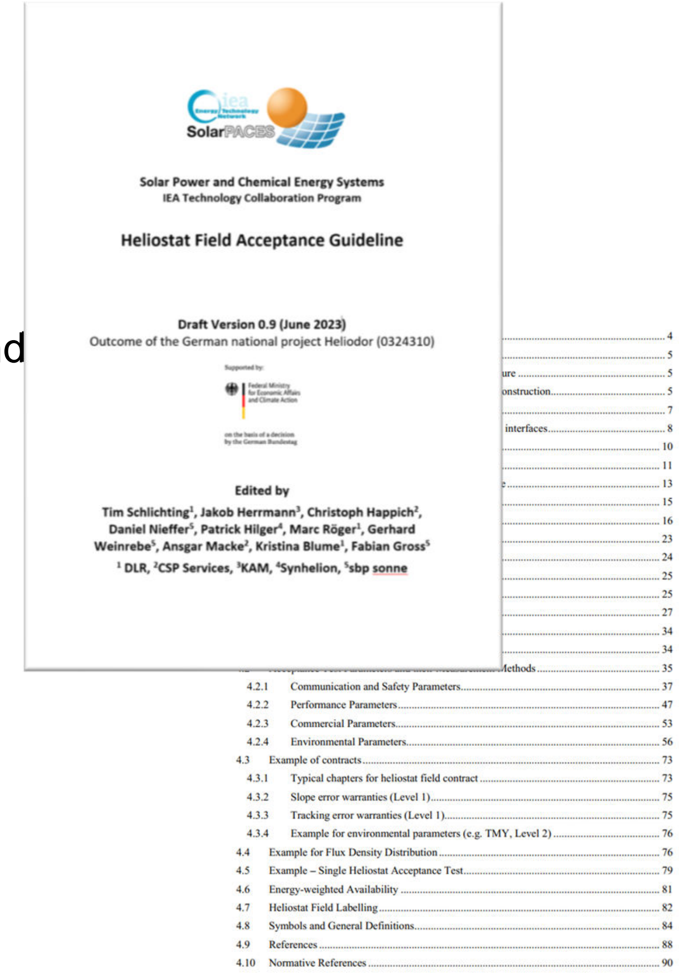
DLR, Solar Field Juelich

# Heliostat Field Acceptance Guideline
## Overview

# 1. Objective
## Heliostat Field Performance Acceptance Guideline

### Objective

- The guideline shall lead to **reliable**, **high quality heliostat fields**
- by defining an **acceptance procedure** to determine the **heliostat field performance.**
- It proves **compliance with contractual agreements** between owner and manufacturer (Example of contract is available).
- The **separation between the tower and the heliostat field efficiency** is of high importance to the manufacturer, yet it has not been standardized so far.

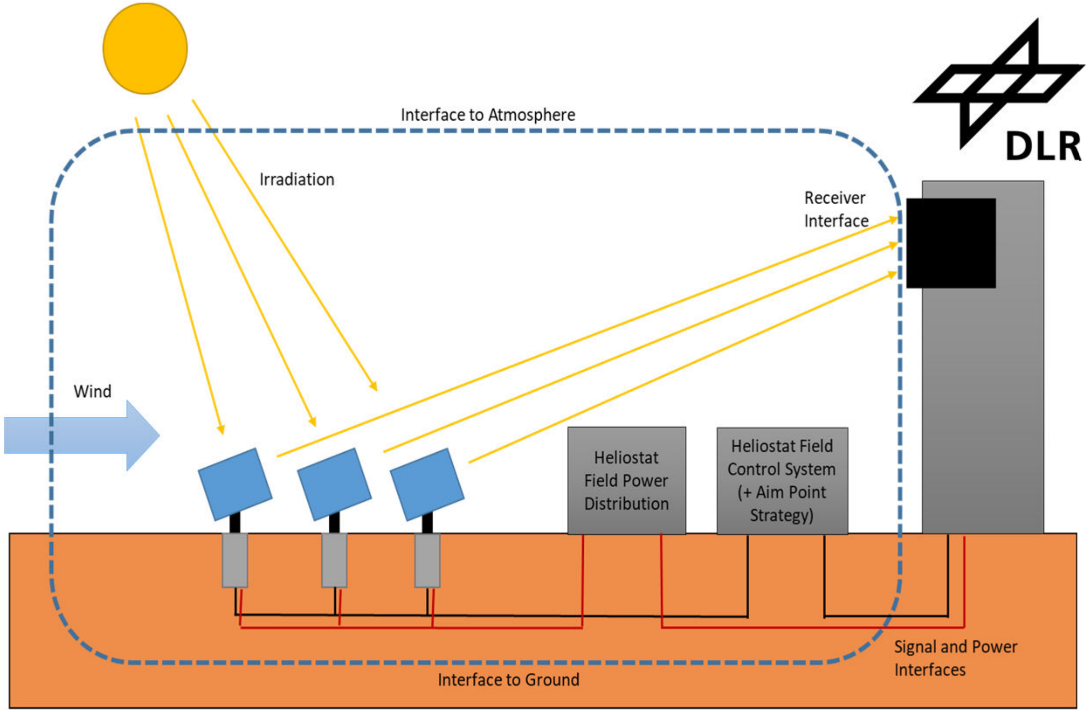



### Status

- Guideline development **started in 2019** within German project consortium HELIODOR: DLR, CSP Services, KAM, Synhelion, sbp Sonne
- Pending: **International review pending** (task III heliostat working group, document to be sent)

# 2. Definitions

- Definition of system boundaries / interfaces




- Definitions of parameters in the categories of
  - Performance
  - Commercial
  - Communication & Safety
  - Environment

**Performance Parameter**
- Tracking Accuracy
- Slope Error
- Reflectivity
- Reflective Area
- Flux Density Distribution
- Aimpoint Strategy
- Heliostat Field (Yearly) Efficiency
- Availability
- Field Layout
- Energy Consumption
- Time Limits
- Operational Limits

**Commercial Parameters**
- Operating Costs
- Maintenance & Repair Costs
- Cleaning Costs
- Lifetime
- Degradation
- Required Standards Guidelines and Local Regulations

**Comm. & Safety Parameters**
- Functional Safety and Failure Rates
- Flux Limits
- Communication Loss
- Power Loss
- Emergency Defocus
- Emergency Stow
- Emergency Stow Power Demand
- Uninterruptible Power Supply (UPS)
- Reaction Time (Latency)
- Control Failures
- Reaction to Contradictory Commands
- Survival Limits

**Environmental Parameters**
- Date/Time (Flux)
- Latitude
- Longitude
- Height MSL
- Atmosphere (Flux)
- Direct Normal Irradiance (DNI)
- Wind Loads
- Surface Roughness
- Operational Limits
- Survival Limits
- Thermal Loads
- Survival Limits
- Air Humidity and Dust
- Sunshape (Flux)
- Extinction
- Hail
- Snow
- Lightning
- Ground

# 2. Definitions
## Categories of parameters regarding their method of estimation

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**Each parameter can be assigned to at least one of the following categories:**

- **AT- Acceptance Test:** Parameter derived by short term field test (e.g. heliostat slope deviations after commissioning of the field)
- **MP- Mathematical Proof:** Based on measured data, further calculation steps must be made to derive this parameter (e.g. yearly energy output in MWh)
- **TE- Time Evaluation:** Parameter which has to be observed over time by multiple measurements or operational data (e.g. heliostat availability)
- **PT- Component Pre-Test**: Not every part or component can be tested in the field, e.g. lifetime of components. They must be measured in laboratory prior to shipment (e.g. mirror ageing)
- **QC- On-site manufacturing quality control:** Parameter which are derived during the heliostat manufacturing (e.g. inline slope deviation measurement).

# 3. Methodology

The guideline offers **different options** for an acceptance test in a **contractual agreement**:

- Heliostat properties only (level 1)
- Simulation based output (level 2, based on level 1)
- Measurement of solar field efficiency $\eta_{sol,field}$ by
  - Integrated solar flux measurement over receiver aperture
    $\eta_{sol,field} = \boxed{P_{in,aperture}} / \Sigma(G_b * A_{net} * \rho_{s,\theta} * \xi)_i$
    *High uncertainties >6-8%*
  - By measuring total efficiency (solar → thermal output) and the thermal receiver efficiency:
    $\eta_{sol,field} = \eta_{total} / \boxed{\eta_{th,rec}}$
    *Needs receiver and its thermal efficiency; accuracy of PowerOn/Off test?*

# 3. Methodology



The guideline offers **different options** for an acceptance test in a **contractual agreement**:

- Heliostat properties only (level 1)
- Simulation based output (level 2, based on level 1) *Level 2 recommended*

- Measurement of solar field efficiency $\eta_{sol,field}$ by
  - Integrated solar flux measurement over receiver aperture
    $\eta_{sol,field} = P_{in,aperture} / \Sigma(G_b * A_{net} * \rho_{s,\theta} * \xi)_i$ *High uncertainties >6-8%*
  - By measuring total efficiency (solar → thermal output) and the thermal receiver efficiency:
    $\eta_{sol,field} = \eta_{total} / \eta_{th,rec}$ *Needs receiver and its thermal efficiency; accuracy of PowerOn/Off test?*

# 3. Methodology
## Different levels of performance acceptance

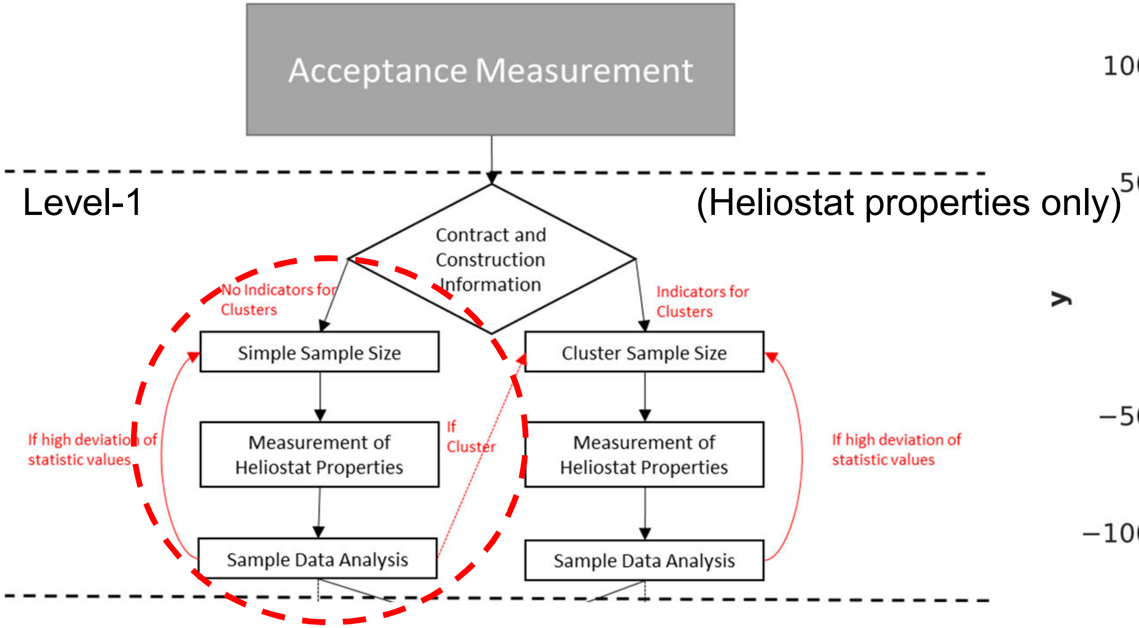
| | Heliostat properties only (level 1) |
|---|---|
| Acceptance Procedure | Define sampling method and measure individual heliostats of the sample |
| Contract | Comply measured heliostat parameters (e.g. distributions of tracking error, slope deviation, etc.) with the contractual design values? within conf.intervall |
| Complexity | Moderate |
| Uncertainty of field performance result | Depends on sample size |
| Limitations | Not considered are:<br>- Field layout effects<br>- Aimpoint strategies |

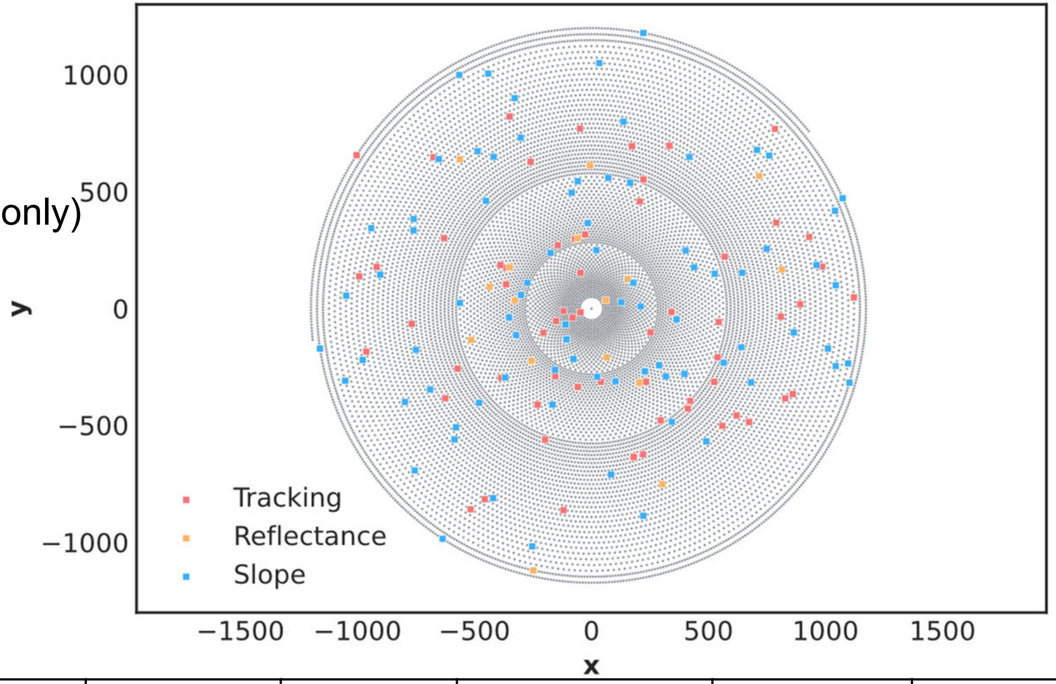
# 3. Methodology
## Different levels of performance acceptance

*Level 2 recommended*

| | **Heliostat properties only (level 1)** → | **Simulation based output (level 2)** |
|---|---|---|
| Acceptance Procedure | Define sampling method and measure individual heliostats of the sample | Define sampling and measure individual heliostats.<br>Level2: Data analysis (Anomalies), data extrapolation on not measured heliostats and raytracing simulation |
| Contract | Comply <u>measured</u> heliostat parameters (e.g. distributions of tracking error, slope deviation, etc.) with the <u>contractual design values</u>? within conf.intervall | Comply the <u>“sim.based”</u> heliostat field efficiency, or heliostat field yield (*yearly/monthly/daily MWh*) with the <u>contractual design value</u>? within conf.intervall |
| Complexity | Moderate | More complex, additional simulation step |
| Uncertainty of field performance result | Depends on sample size | Uncertainty ~ 3 % (with sufficient sample size and hi-fidelity raytracer) |
| Limitations | Not considered are:<br>- Field layout effects<br>- Aimpoint strategies | - Aimpoint strategy is considered - must be defined in contract<br>- Raytracer validated and the same used for contract and acceptance calculation |

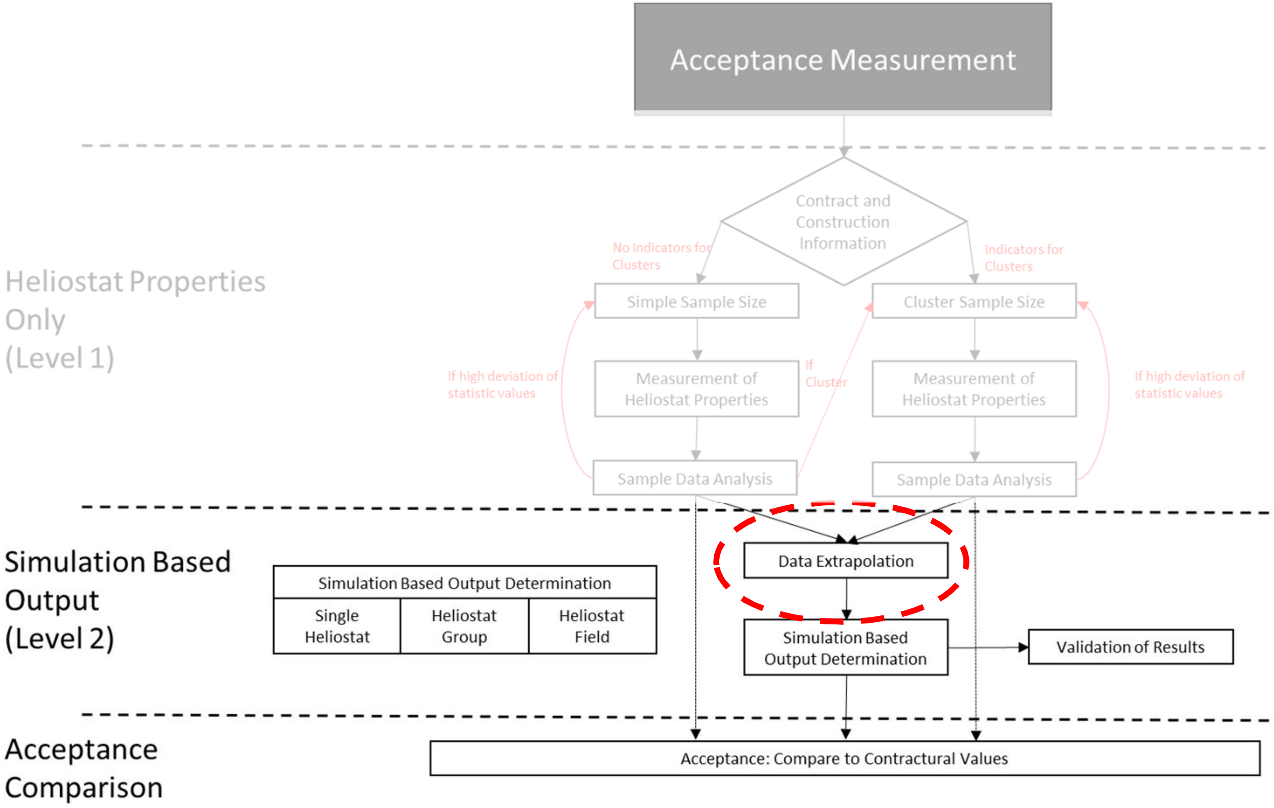
# 4. Field Acceptance Procedure
## Theoretical Example - Sampling



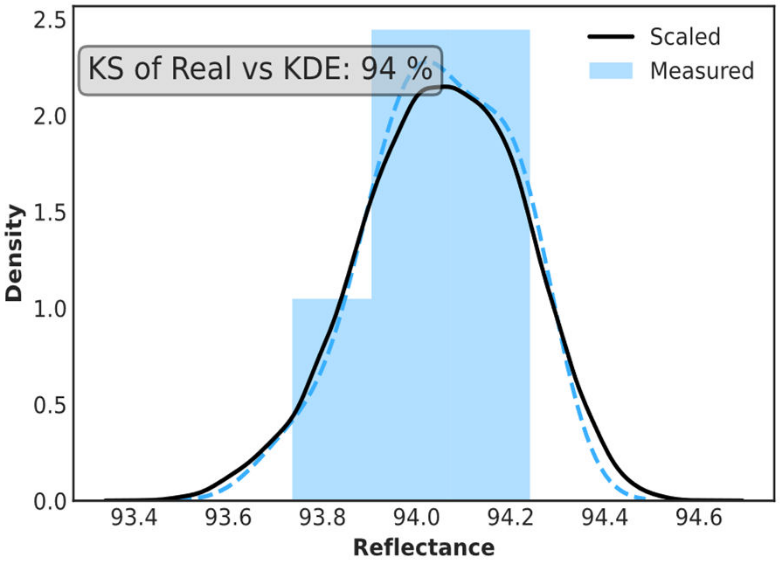

| Parameter | Estimated standard deviation ($\sigma_e$) | Estimated mean ($\mu_e$) | Estimated coefficient of variation ($V_e$) | Relative error margin (e) | Sample size |
|---|---|---|---|---|---|
| Slope Error | 0.3 mrad | 1.3 mrad | 0.23 | 5 % | 81 |
| Tracking Accuracy | 0.2 mrad | 0.5 mrad | 0.4 | 10 % | 61 |
| Reflectance of clean mirror | 0.2 % | 94 % | 0.002 | 0.1 % | 17 |

# 4. Field Acceptance Procedure
## Theoretical Example – Data extrapolation (scalar)




Scalar values:

- Data Extrapolation to not measured heliostats using *Kernel Density Estimation*
- PDF must remain the same

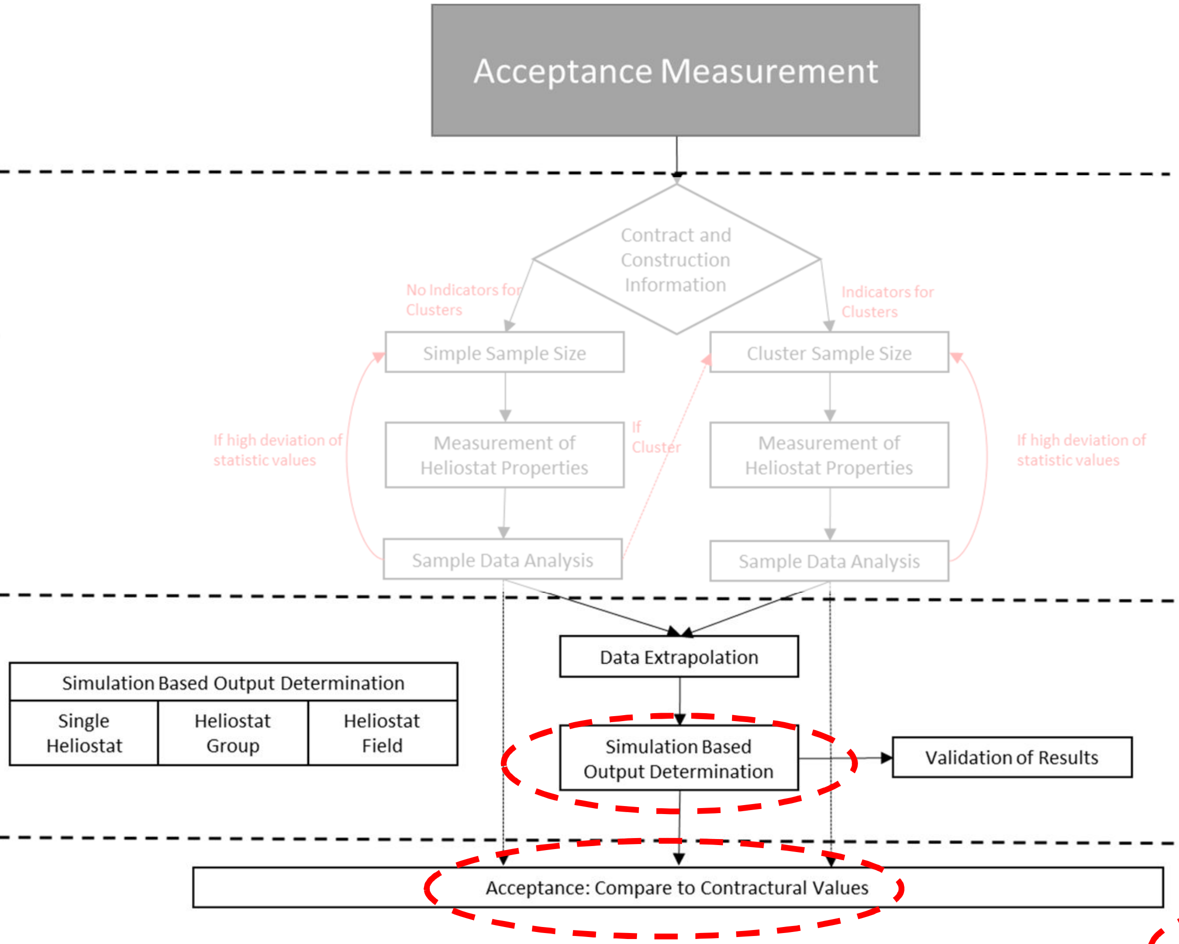


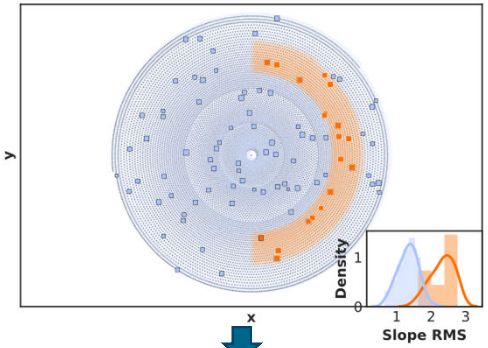
# 4. Field Acceptance Procedure
## Theoretical Example – Simulation and comparison with contract

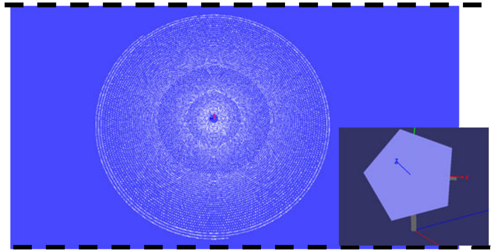
Heliostat Properties Only (Level 1)

Simulation Based Output (Level 2)

Acceptance Comparison

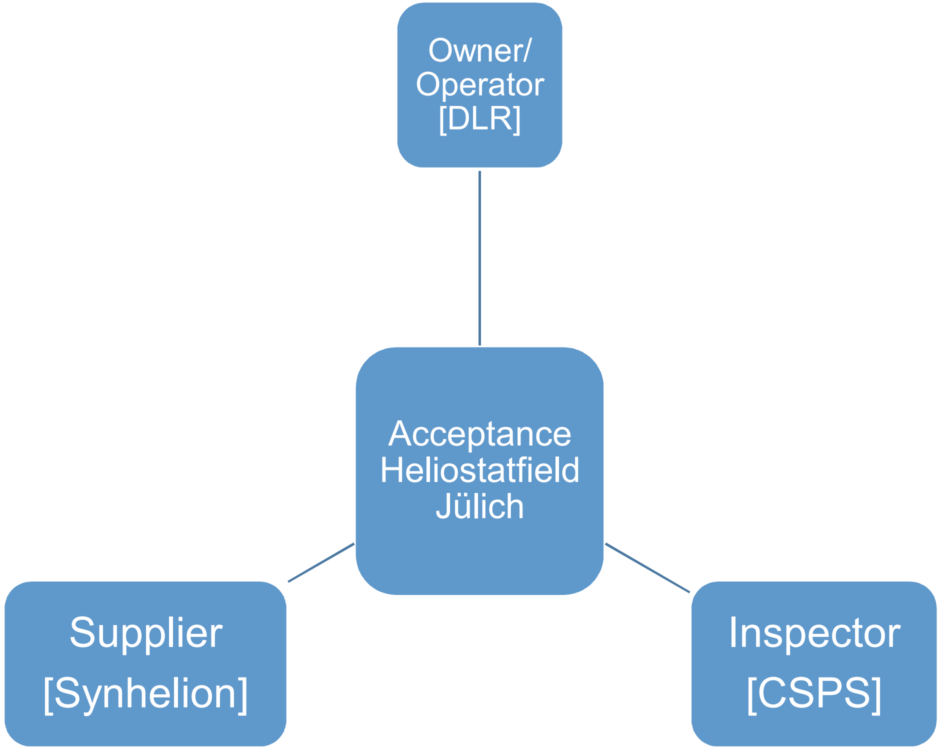


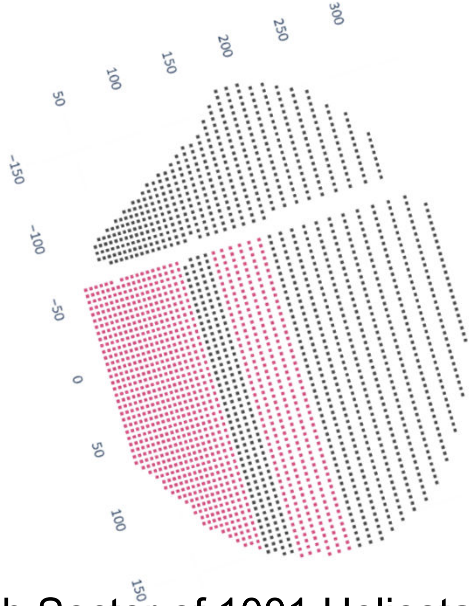



Yearly MWh in receiver
Solar field efficiency

# 5. Field Acceptance Procedure
## Practical Exercise: Exemplary Acceptance Testing Jülich




Heliostat Field Juelich

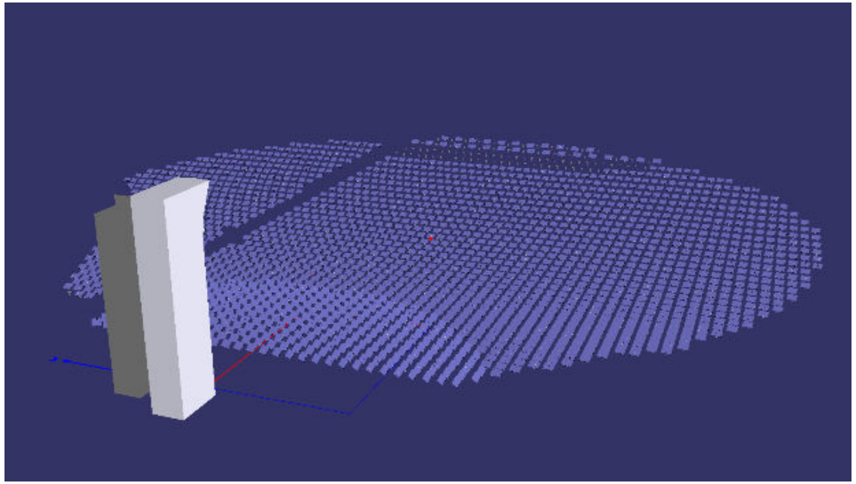



Sub Sector of 1001 Heliostats

# 5. Field Acceptance Procedure
## Practical Exercise: Exemplary Acceptance Testing Jülich

- Lessons learned & included in guideline:
  - Acceptance went smooth
  - SW reflectance better from lab measurements [PT], only variation from field measurements [AT]
  - Confirmation: Geometrical performance parameters have high priorities
  - Cluster analysis detected area of bad calibrated heliostats
  - Development of faster measurement of tracking accuracy was included in guideline

- Publication of exemplary acceptance testing planned for beginning of 2025



# Conclusion
## Heliostat Field Performance Acceptance Guideline

- The guideline defines **acceptance procedures** to determine the **heliostat field performance** and proves **compliance with contractual agreements** between owner and manufacturer
- Based on **statistical samples of heliostat individuals**
- The performance of **heliostat individuals** uses the **SolarPACES Heliostat Performance Testing Guideline**
- The measured values are **extrapolated to the whole field** and a **raytracer** calculates **hourly or yearly efficiencies**
- The simulated power can be **validated** by flux measurements of individual heliostats or groups
- The viability of the approach has been **tested at the Solar Tower Juelich**


Solar Power and Chemical Energy Systems
IEA Technology Collaboration Program

Heliostat Field Acceptance Guideline

Draft Version 0.9 (June 2023)
Outcome of the German national project Heliodor (0324310)

on the basis of a decision by the German Bundestag

Edited by

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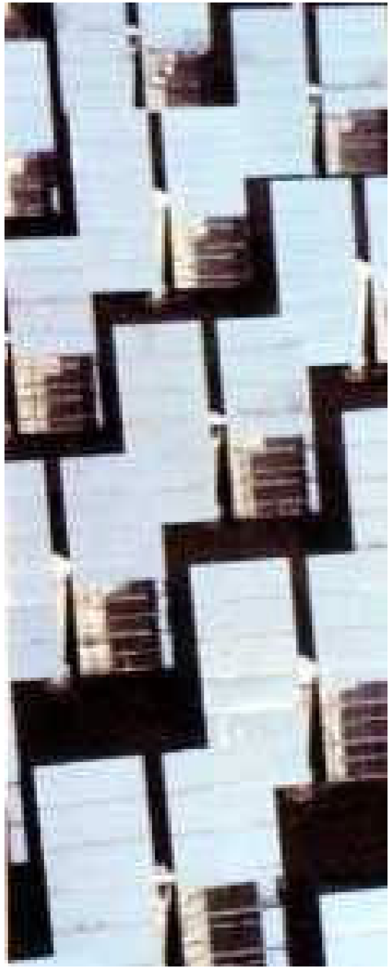
**Watch out for journal publications**

Heliostat Field Acceptance Guideline



## Funding Agencies

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AnalyzeHeliostatField

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THANK YOU for your attention
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