After the RISEnergy Transnational Access, Users are required to submit a User Report. This should be done within 4 weeks after the Access is completed unless otherwise agreed. The User Report will be given to the User(s) by the WP2 leader. The report contains sections related to the work performed, the main results and observations that were achieved.

This document should be completed, signed, and sent by e-mail to risenergy@for.kit.edu*.*

Summary questionnaire for Users who have been granted Transnational Access (TA) under the RISEnergy project Horizon Europe TA scheme. More information on RISEnergy TA can be found in "General Rules" and in "Access Policy" which can be found on the RISEnergy webpage.

Please complete, sign, and send this form, together with the Cost claim by e-mail to risenergy@for.kit.edu *with title: RISEnergy APPXXX - reports.*

General information about the project	
Project title (as used in Application)	Tests of closed-loop control of heliostats, using retroreflectors
Project number (APPXXX) and acronym (max 15 characters)	APP165
RISEnergy RI(s) accessed	DLR-CSP-STJ-RP
Keywords (up to five, free text)	CSP, Heliostat, closed-loop, precision alignment, retroreflector
Arrival date (in town where RI is located)	2025-08-25
Departure date (from town where RI is located)	2025-11-06
Starting date of Access (first day at RI)	2025-08-25
Finishing date of Access (last day at RI)	2025-10-31
Number of days not using the RI (during the above period)	45
Reason for not using RI those days (describe)	Inclement weather, personal (death in family), travel
Number of days using the RI	22
Number of Users granted Access (group size)	2

Comments	Users commuted from home to DLR on each of the access days. Arrival/departure refer to the first and last days of these commutes
User	
User group leader or sole applicant (user group member 1)	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
User group member 2	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
User group member 3	
First name	
Last name	
Affiliation / Employer	
Country of Employer	
E-mail	
User travelling to RI?	
Comments	
User group member 4	
First name	
Last name	
Affiliation / Employer	
Country of Employer	

E-mail	
User travelling to RI?	
Comments	

Please insert more fields if your groups had more than four members.

Access Summary Report - work performed and initial results

Brief description of the objectives of your project (up to 200 words)

The project is split into two phases. This report covers only Phase 1, which concluded at the end of October 2025. Phase 2 will commence in the summer of 2026.
The objectives for Phase 1 were to demonstrate installation of the closed-loop system in a real CSP environment, and to assess its operation therein.
Specifically, this comprises:
1) Installation of retroreflectors ('retros') in front of the solar- receiver aperture and document the effort for doing so;
2) reflectivity modulation of the retros in that location;
3) installation of a photosensor in front of a heliostat and document the effort for doing so;
4) receiving signals, i.e., the reflected light from the retroreflectors with modulation evident;
5) show how the received modulated-signal strength depends on the pointing of the respective heliostat;
6) test integration of the closed-loop system into the local heliostat controls;
7) demonstrate the modularity and scaling properties of the system.

Further objectives of Phase 2 are to operate the system at the full solar irradiance of the order of 1 MW/m^2.

Activities performed (up to 600 words)

Activities oriented towards Phase-1 goals:

1) Retro installation:
An aluminium frame was installed in front of the solar-receiver aperture at the 'Forschungsebene' on the solar tower (an interim solution for Phase 1).
Three retro assemblies were mounted on glass plates inserted into this frame. Pumps for moving the working fluid (water in Phase 1) for effecting the modulation were set up inside behind the heat-shield wall of the receiver, together with a small computer (Raspberry Pi and Arduino) for controlling the pumps.

Installation of the frame and one retro took 4 hours for three persons (two from Heliosync and one local from DLR). Two more retros were mounted later, each taking about 2 hours of one Heliosync person.

2) Reflectivity modulation
The pumps were pushing/pulling the working fluid into/out-of the retros at rates of up to about 1 Hz. The computer for controlling the pumps was accessed remotely from Heliosync's main control computer.

3) Installation of photosensor
An augmented photosensor assembly was built for the purposes of the tests, comprising the photosensor electronics (a photodiode, simple signal-conditioning circuitry, and a digitizer), and a camera for obtaining video data of the retros simultaneously with the photosensor receiving the modulated signals. This assembly, a 100-mm-long lens tube on an optical beamsplitter with the photodiode/signal-conditioner and the camera attached to its two outputs, total size about 150mm by 60mm by 30 mm, was mounted on a tripod in front of the heliostat used. During each test day, the photosensor had to be moved between heliostats to avoid shadows cast by the solar towers.

Setting up and aligning the photosensor assembly on each of the test days took about 1/2 hour. In future operation at a CSP facility, this will need to be done only once, and the assembly will be smaller, consisting of only a lens tube and the photodiode/signal-conditioner electronics, but lacking the camera.

4) Receiving signals
Modulated-light signals from the retros were recorded in digitized form. The signal-conditioner circuitry on the photosensor removes he considerable constant-light component due to the overall brightness of the solar receiver, and passes to the digitizer only the variable part comprising the modulation and other seconds-scale variations mainly due to shifting clouds. Typical signal waveforms in raw and Fourier-transformed form are shown in a separate detailed technical report.

5) Dependence of signal on heliostat pointing
The heliostats were operated in open-loop tracking mode while small, milli-radian-scale offsets were applied to move their radiant footprints across the retros. The signal strength was recorded as a function of angular offset.

6) Test integration
DLR IT security did not permit a direct connection between Heliosync's and DLR computers. Therefore, heliostats were controlled manually through DLR's user interface, and data were correlated by use of timestamps.
A python script was written to raster the heliostat motion in two dimensions (two pointing angles), but was not used for lack of time (see below).
A procedure was discussed with DLR staff for establishing heliostat control and data communication between Heliosync's and DLR's computers while satisfying the IT-security requirements.

7) Modularity and scaling
The modularity of the system was demonstrated by installing retros in phases, i.e., first one with the frame, and then two more on later days, and by setting up and moving

the photosensor assembly frequently during each test day.
An important aspect of scaling is the cross-talk, i.e., a photosensor on one heliostat receiving signals due to light reflected onto the solar receiver by other heliostats (ideally none). This was tested by recording signals on one heliostat while multiple other ones were also reflecting onto the receiver.

Scientific results (up to 800 words)

1) Installation effort:
It was shown that the retros with their associated pumps can be installed on the tower of a CSP facility, and that the on-site effort is of the order of hours. Even though the aluminium frame used for the Phase-1 tests is not suitable for operation at the full irradiance of the order of 1 MW/m^2, the result is still of practical relevance for calibration (see below).
The full-irradiance tests in 2026 are oriented towards the most ambitious goal of continuous and simultaneous closed-loop operation of heliostats without any interruptions.
However, a lesser goal of providing the means of intermittently calibrating heliostats in batches of tens to a hundred (instead of one-at-a-time), can be reached with the current way of mounting the retros in a reference region near the solar receiver. Interest in such a way of operating the system was, in fact, expressed by a potential customer.

2) Reflectivity modulation:
It became clear that the use of water as a working fluid has two disadvantages:
i) Water, with its refractive index of 1.33 vs. 1.43 of the glass does not suppress the total reflection at all incidence angles. This limits the angular range within which the modulation is apparent;
ii) the water does not cleanly detach from the glass of the retro when, in each pump cycle, it is withdrawn from the retro. Droplets still remain, which reduce the reflectivity, thus limiting the dynamic range of the modulation.
Both of these problems are not serious. Number i will be addressed by use of a higher-index working fluid, and no. ii will become irrelevant with the future way of operating the modulation, which is currently under development: instead of injecting and withdrawing the working fluid, it will be evaporated and condensed in each cycle. In fact, the pumps used for the Phase-1 tests were already designed to also operate in evaporation/condensation mode.

3) Photosensor installation:
Found to be straightforward to the point of making it routine to relocate and re-align the photosensor.

4) Receiving signals:
Signals from the modulating retros were received clearly, and samples of those are shown in the detailed technical report. However, during most of the test days, a rapidly shifting partial cloud cover was present, which interfered with the signal quality. This

will not be an issue at most other CSP sites (such as in Spain), but it will be addressed, nonetheless, with improved signal conditioning.
Wind-induced shaking of heliostats was also found to degrade signal quality.

5) Dependence of signal on heliostat pointing:
This is at the core of the closed-loop concept. Because full closed-loop operation was not possible under the constraints of DLR's IT-security protocols, the heliostat-pointing offsets were controlled manually, and signals were recorded with corresponding timestamps. A clear dependence of the signal strength on heliostat pointing was observed and recorded (see detailed technical report):
For a heliostat close to the tower, its radiant footprint on the receiver corresponds rather directly to the shape of the mirror (or multiple segment mirrors). A strong signal from a modulating retro was observed only when the part of the radiant footprint was present on the receiver, which corresponded to the location of the photosensor in front of the heliostat mirror.
More generally, the radiant footprint is a convolution of i) the directly projected image of the mirror(s) with ii) the 8-mrad angular size of the solar disk times the heliostat-tower distance. This is relevant for heliostats farther removed from the tower (not tested in Phase 1). However, even then, Heliosync's system can, in principle, achieve an accuracy of 0.02 .. 0.05 mrad by making used of the contrast at the edge of the solar disk (see literature referenced in the proposal). Proof of that assertion will be given in Phase 2, or a Phase 1a, if approved.

6) Integration into heliostat controls:
Due to IT-security constraints, it was not possible to integrate Heliosync's controls into those of DLR, and manual operation was required for data-taking. However, in the course of discussions with DLR staff, a possible solution was found to establish a limited, but sufficient level of inter-system communication, while satisfying IT security. This solution will be a valuable template for implementing control access at other facilities.

7) Modularity and scaling:
It was shown that, at least with the low-irradiance mount made of aluminium, adding retros is a straightforward procedure of a few person-hours. Adding photosensors to heliostats is also straightforward, as demonstrated by the frequent relocations and re-alignment of the test sensor.
A measurement of the cross-talk between heliostats was performed by recording the photosensor signal at one heliostat while illuminating the receiver region containing the retros with four other ones. No signal due to the other heliostats was observed.

Interpretation of the results (up to 400 words)

The Phase-1 work performed to-date shows that it is possible to retrofit an existing CSP facility at least with a system capable of calibrating batches of heliostats, instead of one-by-one. The retrofit part of this statement is supported by the rather straightforward installation procedure, and the batch part by the immeasurably low level of cross-talk.

The data support the claim that the retroreflected signals identify a small region of tens of cm across on a heliostat mirror from whence light is reflected onto the respective retro in front of the sunlight receiver. Concerning the claim of 0.02 to 0.05 mrad pointing accuracy, data are still being processed, and will be shown in the detailed technical report and subsequent publications. However, it is clear already that such measurements are made difficult by shifting clouds and hazy conditions, which make the edge of the solar disk ill-defined. Such conditions were largely prevalent during Phase-1 access to the DLR tower, but will be less so at most relevant CSP facilities.

The results do not yet show full closed-loop operation because that would require communication with the local heliostat-control system (to be implemented in Phase 2) and operation at high irradiance (also for Phase 2).

Phase 1 can thus be seen as a first step towards a market-viable product, as well as identifying areas that need further work:
1) need to modulate the retros in evaporation/condensation mode (under development since the Spring of 2025)
2) need to deal with weather conditions: shifting clouds and wind-induced shaking of heliostats degrading the signal quality (see proposed solutions below), and hazy skies degrading the edge contrast of the solar disk, thus impacting the accuracy of pointing measurements (solution below).
3) the system is almost ready for the less-ambitious mode of heliostat batch calibration (as opposed to fully live closed-loop operation).

Main achievements during the TA related work (up to 250 words)

This report covers only Phase 1. Important results are yet to be obtained from Phase 2 in the summer of 2026. Any achievements so far are thus partial relative to the goals.
What was achieved so far is:
1) demonstration of a system that can, in principle, be used for batch calibration of heliostats;
2) exposure to real-world problems, in particular dealing with weather conditions and coming up with possible solutions (below), with IT-security issues constraining integration into local controls, and with administrative problems;
3) practice in retro-fitting a facility with Heliosync's system;
4) obtaining some data showing the accuracy and specificity of measurements with Heliosync's system.

The following achievements are in terms of conceptual solutions developed for specific problems:

Shifting clouds:
1) Go to higher modulation frequencies to better separate changes in illumination conditions from the modulation;
2) improved signal-processing algorithms that take independent measurements of illumination conditions and compensate for their effects;

Wind-induced shaking:
improved signal-processing algorithms that selectively use data, excluding portions degraded by wind and other weather conditions

IT-security requirements:
together with DLR staff, developed a concept for limited, but sufficient communication with local heliostat controls

Responsivity of the local heliostat controls:
Heliostat controls need to slowly and continuously track the sun, and they are not necessarily made for rapid dynamic changes of heliostat pointing, as needed for taking data while scanning heliostat pointing and under adverse weather conditions.
We will develop data-taking procedures for assembling complete data sets from multiple degraded ones.

Data Management

Measured data and a document describing their structure will be made available on the Heliosync web site.
Those data are:
1) signal waveforms as measured by the photosensor;
2) videos of the retros, taken with the camera on the photosensor:
3) time-stamped logs of heliostat pointing;
4) a document explaining the structure of those data.

Bernhard W. Adams will be responsible for the data.

Difficulties during the TA related work (up to 250 words)

None of the points below is meant as criticism of DLR or the local staff. The following difficulties are simply a result of exposure to real-world conditions.

1) Administrative delays:
The start of Phase 1 was originally envisioned for May of 2025. However, there were delays in signing the contract documents, and thus access became possible only at the end of August.

2) Weather conditions:
There were several days with clear skies during September, but during that time, the system was still in the build-up phase regarding both physical installations, and setting up the computing infrastructure.
Then, during the actual measurements in October 2025 favorable weather conditions at the Jülich test site were scarce.

3) Coordination with other measurements at the DLR site:
While Heliosync was using only a few heliostats, other experiments at the adjacent multifocus tower were conducted concurrently. Safety procedures at DLR prohibit removal of the thermal shielding for access to the retros whenever any heliostats are

in operation at the facility. It was therefore necessary to closely coordinate with other teams at the test site to schedule such access.
Furthermore, the heliostat field went into emergency shutdown at least twice in the midst of Heliosync measurements, triggered by a fault condition in the multifocus tower.

4) Response times:
The heliostat controls at DLR respond only with time delays of a few seconds. While this is quite sufficient for routine operation or closed-loop control, it considerably slows down data-taking, where heliostat-pointing scans are done, especially when one needs to respond to rapidly changing weather conditions. We will develop data-taking protocols to better deal with such delayed responses. Controls at other CSP facilities likely have similar characteristics, geared towards slowly tracking the sun, but not for dynamically scanning the pointing.
Having the appropriate data-taking protocols is therefore of general importance at least for characterizing the system and for batch calibration, if not so much for closed-loop control itself.

Intended publications

Besides presenting the raw data and explaining report on the Heliosync web site, we are also going to present the results at conferences (SPIE San Diego, CA and SolarPaces, Germany) and publish in the conference proceedings. We are also planning to publish the results in at least one more technical paper in, most likely, the journal Solar Energy.

Expected impact

This research will help reduce the cost of solar energy by making CSP more efficient and less costly to install.
It will help European competitiveness by providing a market-viable product and by putting Europe in a position to set construction and operational standards regarding CSP.
It will help European cohesion by combining business and engineering work in Estonia and Germany with operation of CSP in Southern Europe.
Follow-up proposals are expected to develop the system further, in particular regarding decentralized power and CST (thermal use of CSP), as well as the development of extremely lightweight and inexpensive heliostats enabled by closed-loop control.

Conclusions / additional comments

[Provide any other comments you might have on your work]

Did you complete the European Commission User questionnaire https://ec.europa.eu/eusurvey/runner/RIsurveyUSERS?

☐ *Yes* ☐ *No*

Feedback – HSE, Ethics and Satisfaction

Please rate on a scale from 1 (excellent) to 5 (poor). Feel free to provide additional comments

Practical information on how to apply for Transnational Access and the overall application process

1 (excellent)	2	3 (neutral)	4	5 (poor)
X	☐	☐	☐	☐

Comment

Information provided, once your project was accepted, on how to proceed

1 (excellent)	2	3 (neutral)	4	5 (poor)
X	☐	☐	☐	☐

Comment

Support received at the site(s) regarding technical/scientific matters and logistics	Have you got sufficient support from the RI staff during the project? If not, please, specify the problems. X *Yes* ☐ *No*

Specail thanls to the local staff for help in navigating the administrative, technical, and safety landscape.

RI extension / upgrades required	In your opinion, is the RI needed to be upgraded? If yes, please give an explanation. ☐ *Yes* ☐ *No*

None specifically related to Heliosync

Problems with local regulations	Have you had any problems with regulations of the visited RI owner (HSE, lab working hours, etc.)? If yes, please, specify X *Yes* ☐ *No*

There were some coordination problems with other on-going experiments, especially being affected by emergency shutoff. However, since these are safety-relevant, there may not be an easy fix.

Health and safety issues	Did you encounter any health or safety issue during your research? Please provide details. ☐ *Yes* X *No*

Please provide details

Environment & Ethics	Did your research involve the use of elements that may cause harm to the environment, to animals or plants? Please provide details. ☐ *Yes* *X No*
Please provide details	
Environment & Ethics	Did your research deal with endangered fauna and/or flora and/or protected areas? Please provide details. ☐ *Yes* *X No*
Please provide details	
Environment & Ethics	Did your research involve the use of elements that may cause harm to humans, including research staff? Please provide details. ☐ *Yes* *X No*
Please provide details	
Environment & Ethics – Dual use	Does your research have the potential for military applications? Please provide details. ☐ *Yes* *X No*
Please provide details	
Environment & Ethics – Misuse	Does your research have the potential for malevolent /criminal/terrorist abuse? Please provide details. ☐ *Yes* *X No*
Quite to the contrary, the closed-loop system makes heliostats seek locations where the modulated retros are, and will thus not enable steering onto other targets.	
Environmental issues	Were any potentially dangerous substances (materials / gases etc.) released into the environment (atmosphere, water, or land)? Please provide details. ☐ *Yes* *X No*
Please provide details	
Ethics issues	Are there any other ethics issues that should be taken into consideration? Please specify ☐ *Yes* *X No*

Please provide details	
Overall impression of communication and interaction after finishing your TA and related work	<table><tr><td>1 (excellent)</td><td>2</td><td>3 (neutral)</td><td>4</td><td>5 (poor)</td></tr><tr><td>X</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr></table>
We would like to thank local DLR staff for helping us perform the experiment above and beyond their obligations, and to find solutions for accommodating us within the local administrative and safety rules.	
Suggestions for facilities not included in RISEnergy which you would use for your research	
[Please provide suggestions for specific type of facilities missing (RI gaps) or measurement / experiments you would like to perform which can not be done on current RISEnergy facilities.]	
Suggestions how RISEnergy can improve future TA programme, how to make the TA more impactful and how to enable the achievement of high TRL levels	
[Your suggestions]	

Feedback – Pro-active Innovation Support	
Awareness	Did you know about the pro-active innovation support of RISEnergy? ☐ Yes ☒ No
[Please specify how you learned about the pro-active innovation support]	
Personal experience	Have you taken advantage of or benefited from the pro-active innovation support? ☐ Yes ☐ No
[*Please provide details*]	
Information/service provided by the pro-active innovation support?	<table><tr><td>1 (excellent)</td><td>2</td><td>3 (neutral)</td><td>4</td><td>5 (poor)</td></tr><tr><td>☐</td><td>☐</td><td>☐</td><td>☐</td><td>☐</td></tr></table>
[*Please provide details*]	

I declare that the above provided information and especially that information on the number of days visited the RI is correct.

☒ *I have read the RISEnergy privacy policy for participation in the RISEnergy TA and consent to participation and the associated data processing.*

Your full name:

Your signature: