SOLEA -
SOLAR ENERGY AUTOPILOT

A Holistic Architecture for Autonomous Solar Thermal Plants

09/16/2026, M. Kuhl and I. Miadowicz, Deutsches Zentrum für Luft- und Raumfahrt (DLR)

One heat source, many applications
CST as a flexible thermal interface

CST TECHNOLOGIES



Photos: DLR · Z22/Wikimedia Commons · Novatec Solar/Wikimedia Commons

SOLAR HIGH-TEMPERATURE HEAT

THERMAL ENERGY STORAGE

Applications specify the heat demand
➢ CST must manage its complexity.

EXAMPLE APPLICATIONS

Dispatchable power
On-demand electricity generation decoupled from solar fluctuations

Industrial process heat
High-temperature heat for continuous and dynamic industrial processes

Solar fuels
Thermal energy for renewable fuel and chemical production

••• further thermal applications

CST must turn variable solar input into **reliable, process-ready heat**.

Why autonomous CST?

Many coupled components under constantly changing conditions

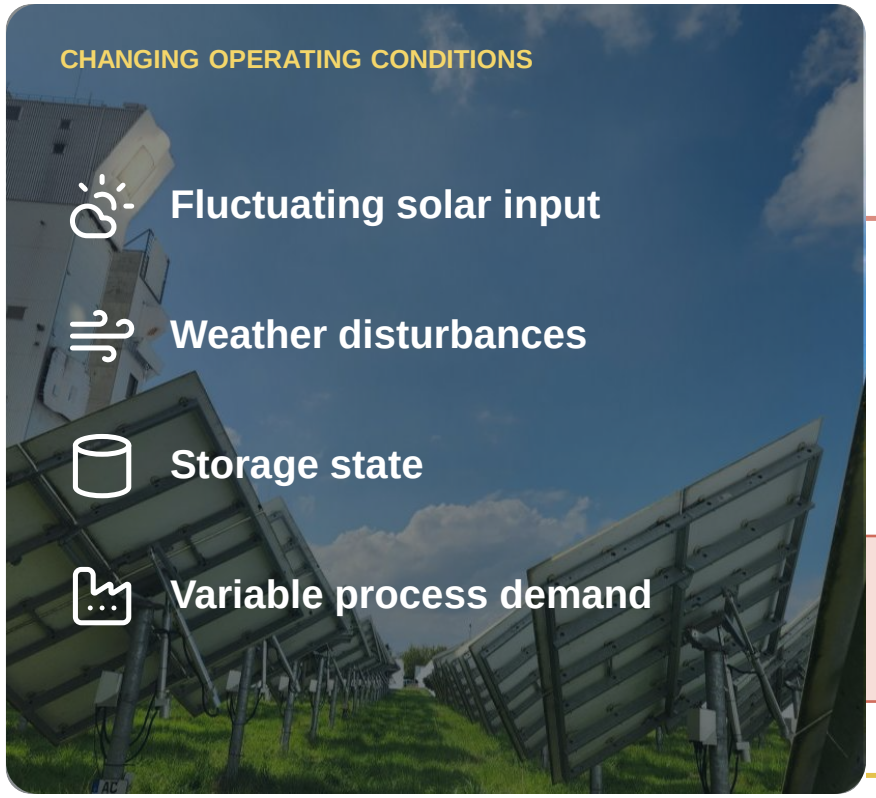
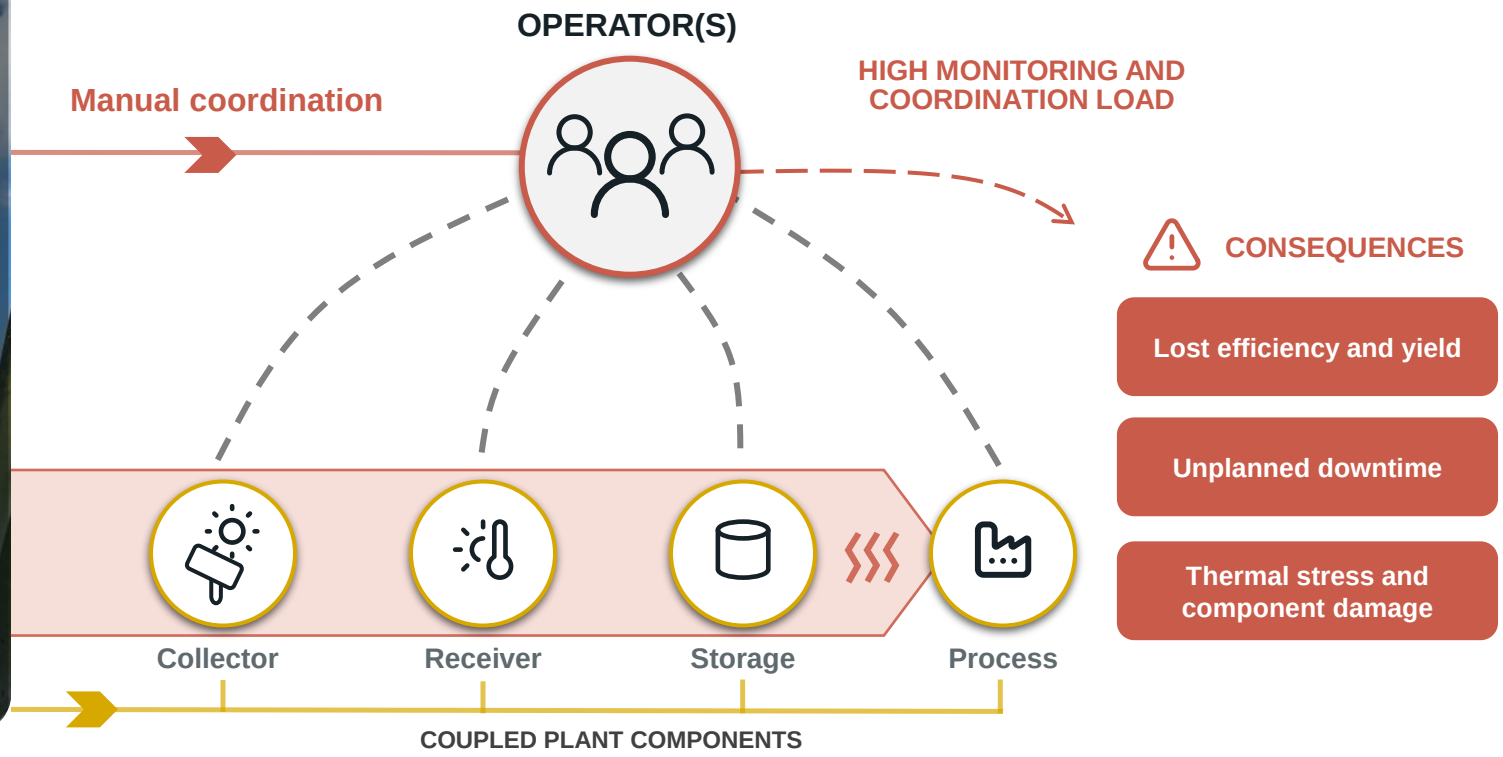
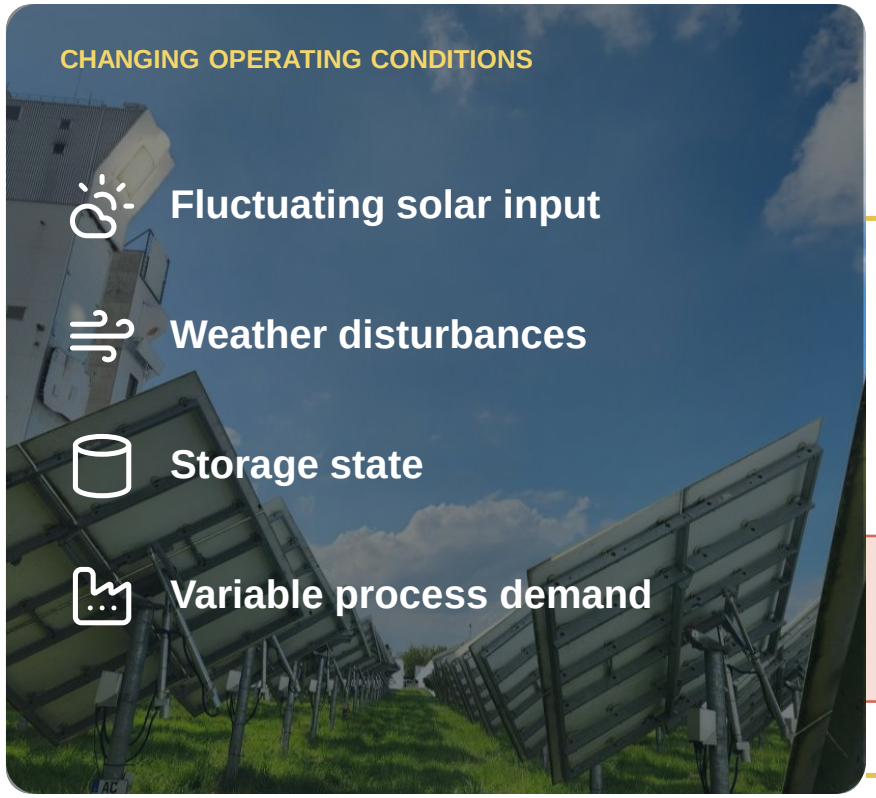


Photo: DLR



Manual coordination cannot keep up with a strongly coupled, constantly changing plant

Why autonomous CST?
Autonomy handles the complexity in real time



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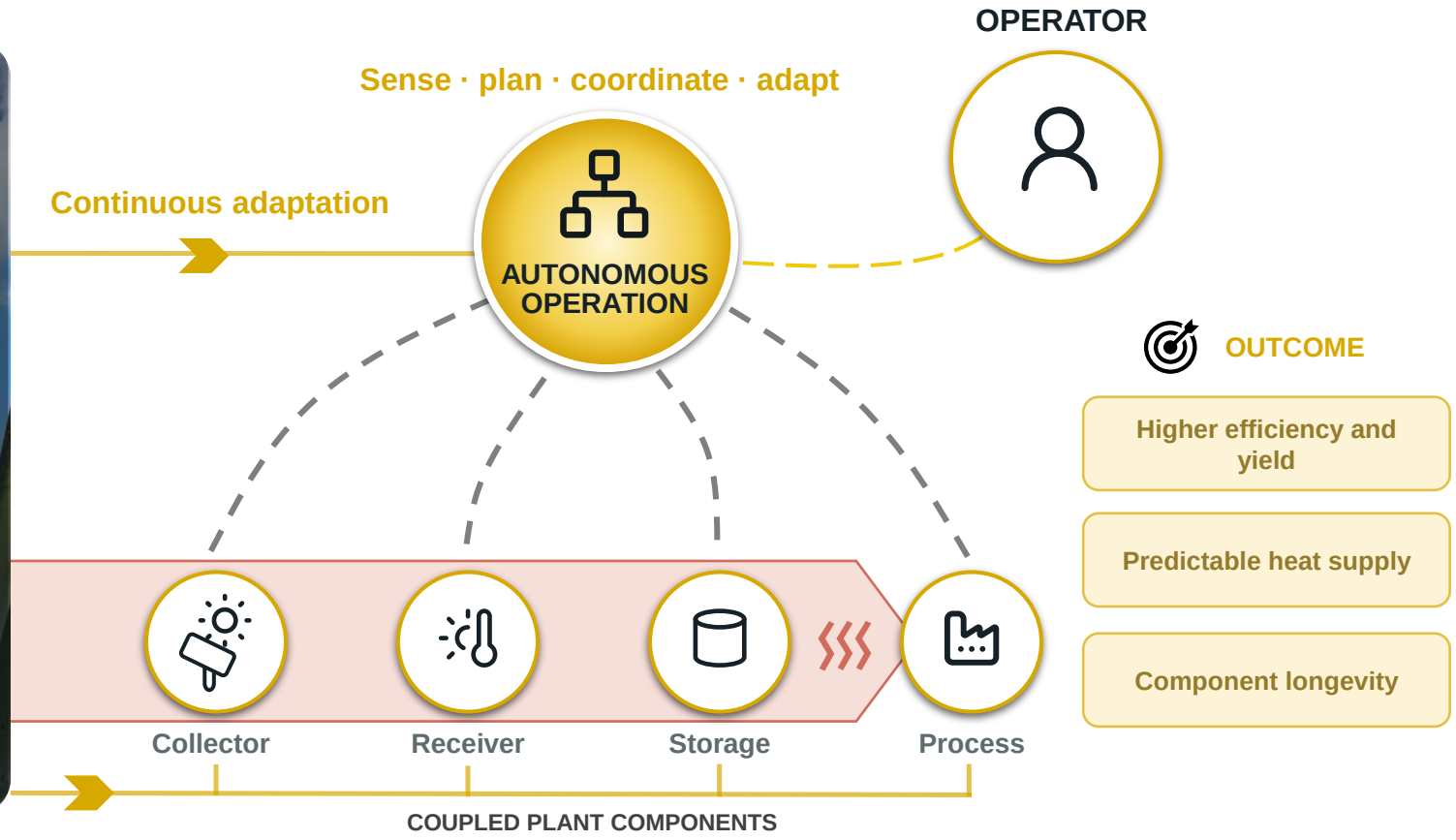


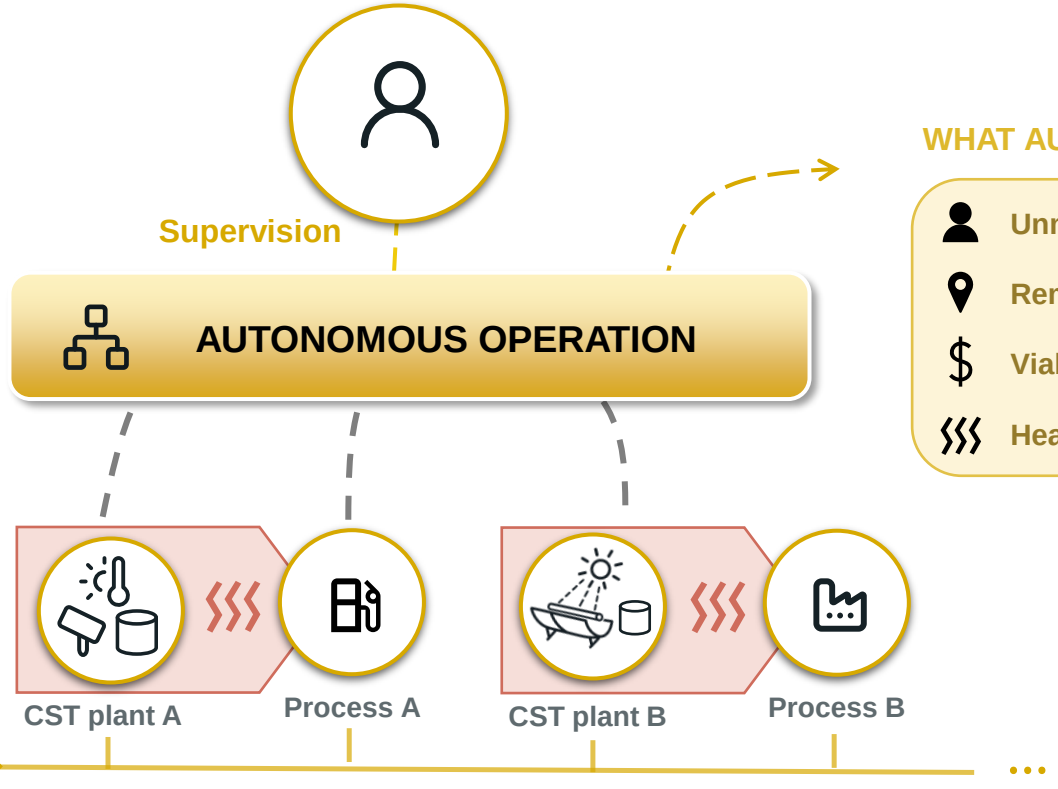
➢ Autonomy manages this complexity to deliver heat reliably and predictably

Greater Vision: CST as a standardized heat source

Autonomous operation supervises a fleet of distributed plants



Photos: DLR · Z22/Wikimedia Commons · Novatec Solar/Wikimedia Commons



WHAT AUTONOMY UNLOCKS

- Unmanned operation
- Remote and off-grid sites
- Viable at small scale
- Heat as a service

➢ CST becomes a standardized building block – reliable heat, delivered as a service

SOLEA Architecture
High-level overview of the holistic concept

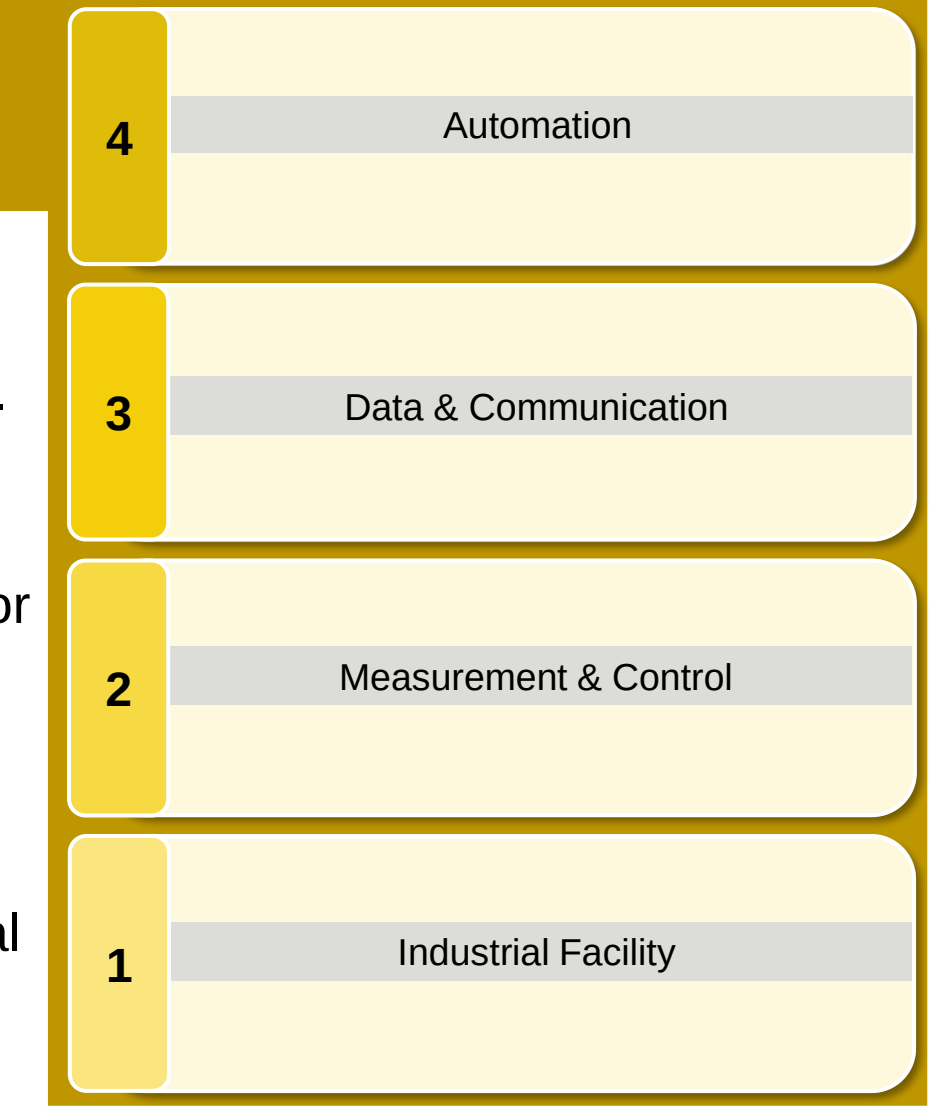
Solar **E**nergy **A**utopilot

Pre-Print: https://dx.doi.org/10.2139/ssrn.6674762

Idea: Synthesize innovations from research and industry to gradually achieve autonomous operation.

Approach: Holistic, modular, and generic concept for intelligent, plant-wide control of existing and newly build CST plants.

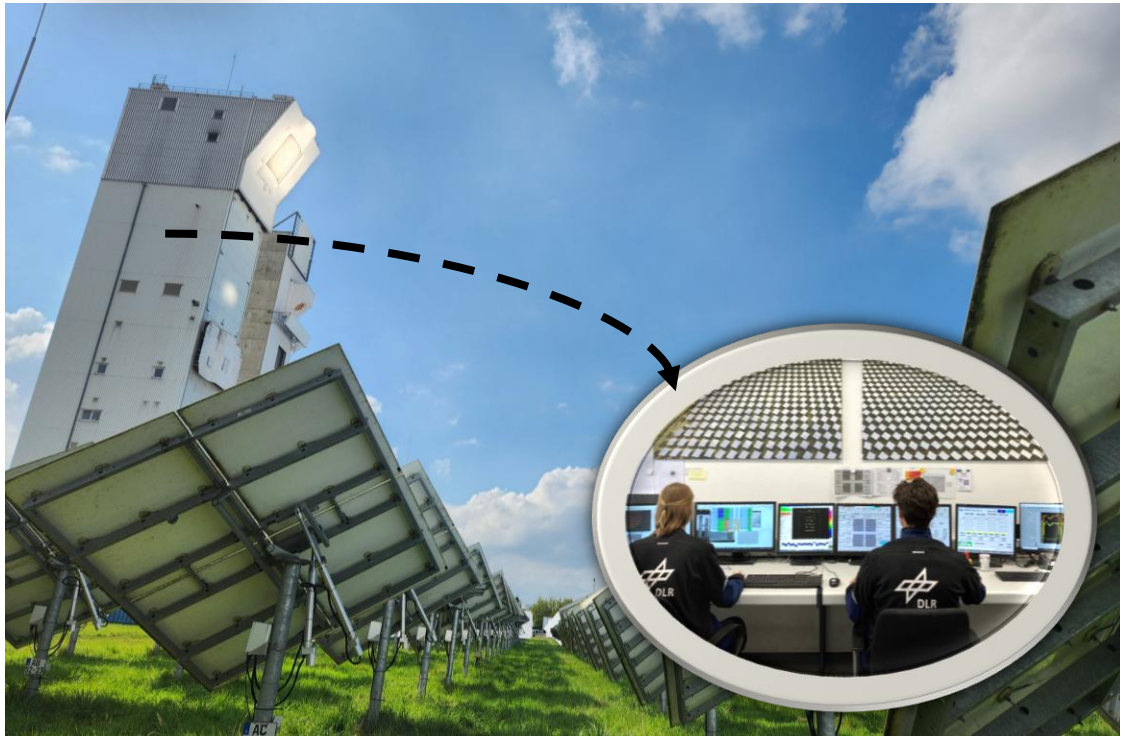
Solution: 4-layer architecture for integrating physical and virtual resources into a c*yber-physical system.*



SOLEA Architecture
High-level overview of the holistic concept

Solar **E**nergy **A**utopilot

1. **Industrial Facility:** Physical Plant Components



4 Automation

3 Data & Communication

2 Measurement & Control

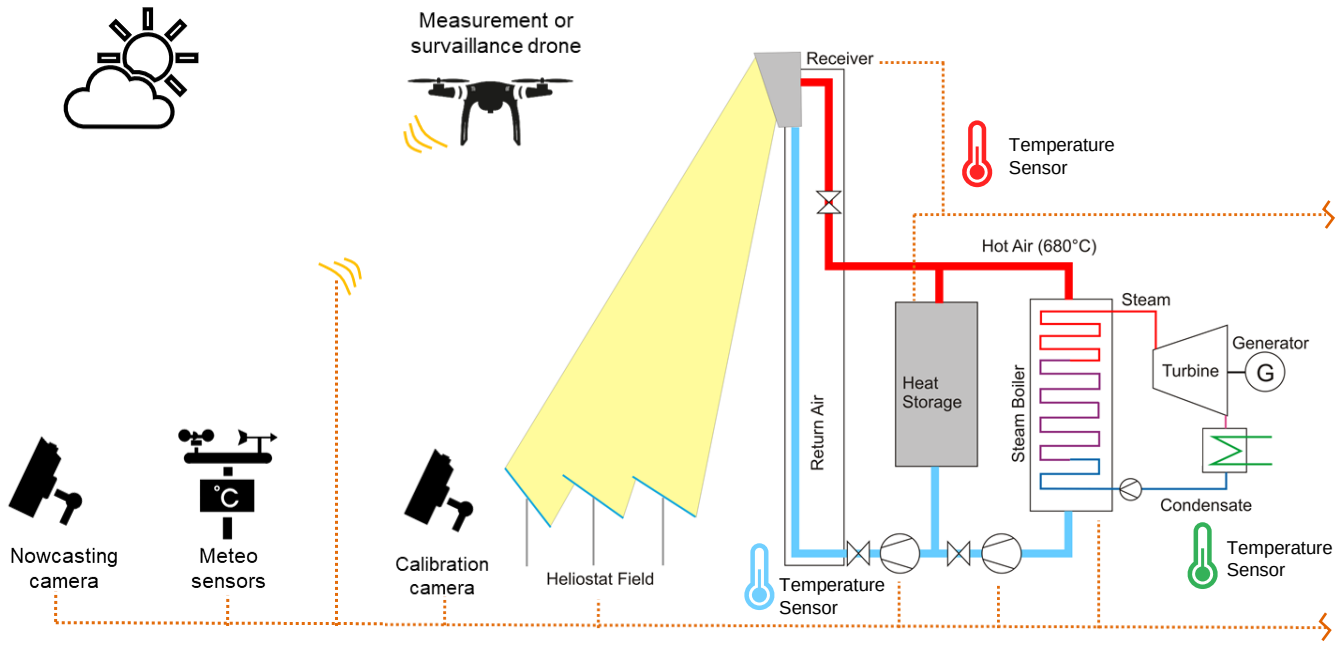
1 Industrial Facility

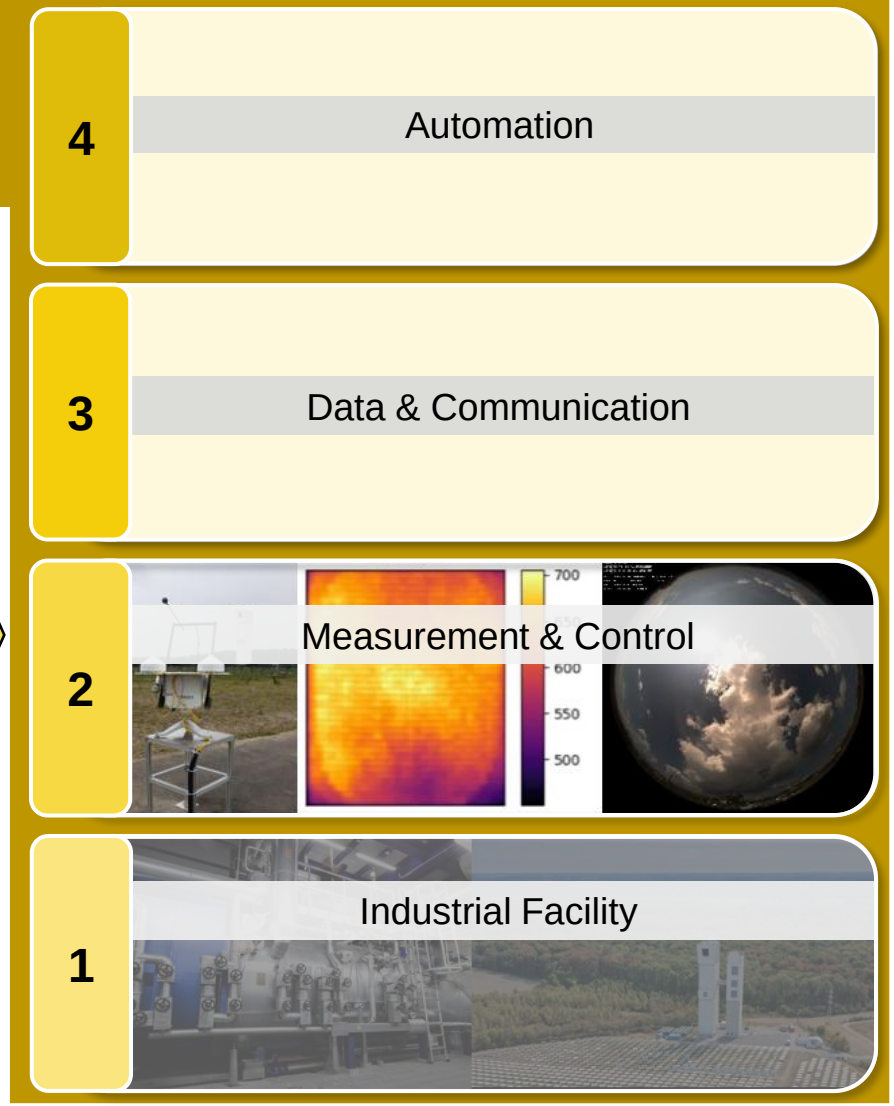


SOLEA Architecture
High-level overview of the holistic concept

Solar **E**nergy **A**utopilot

2. Measurement & Control Systems: Data collection & control of physical components





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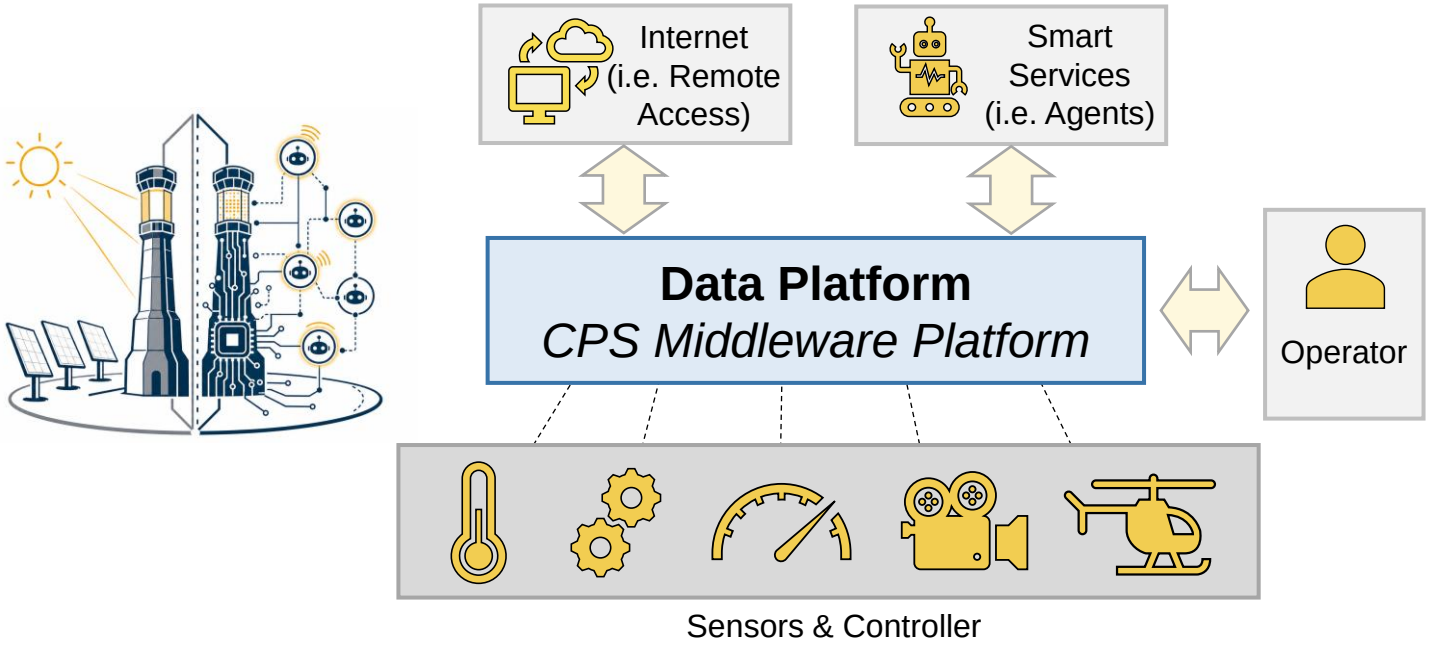
3. Data & Communication: Digital-Twin-based data consolidation & integration
(Article: https://doi.org/10.1016/j.seja.2025.100102)

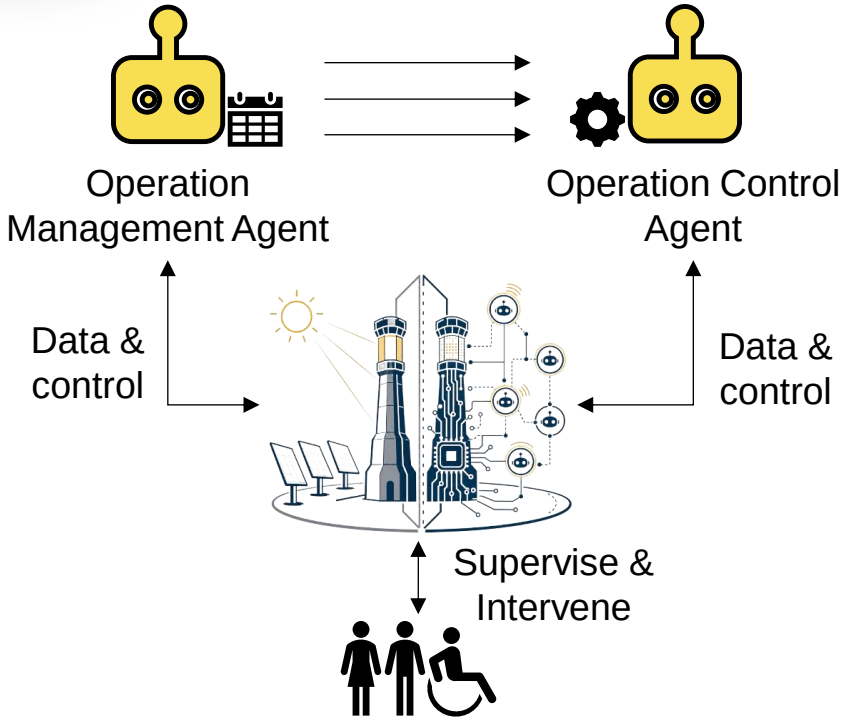


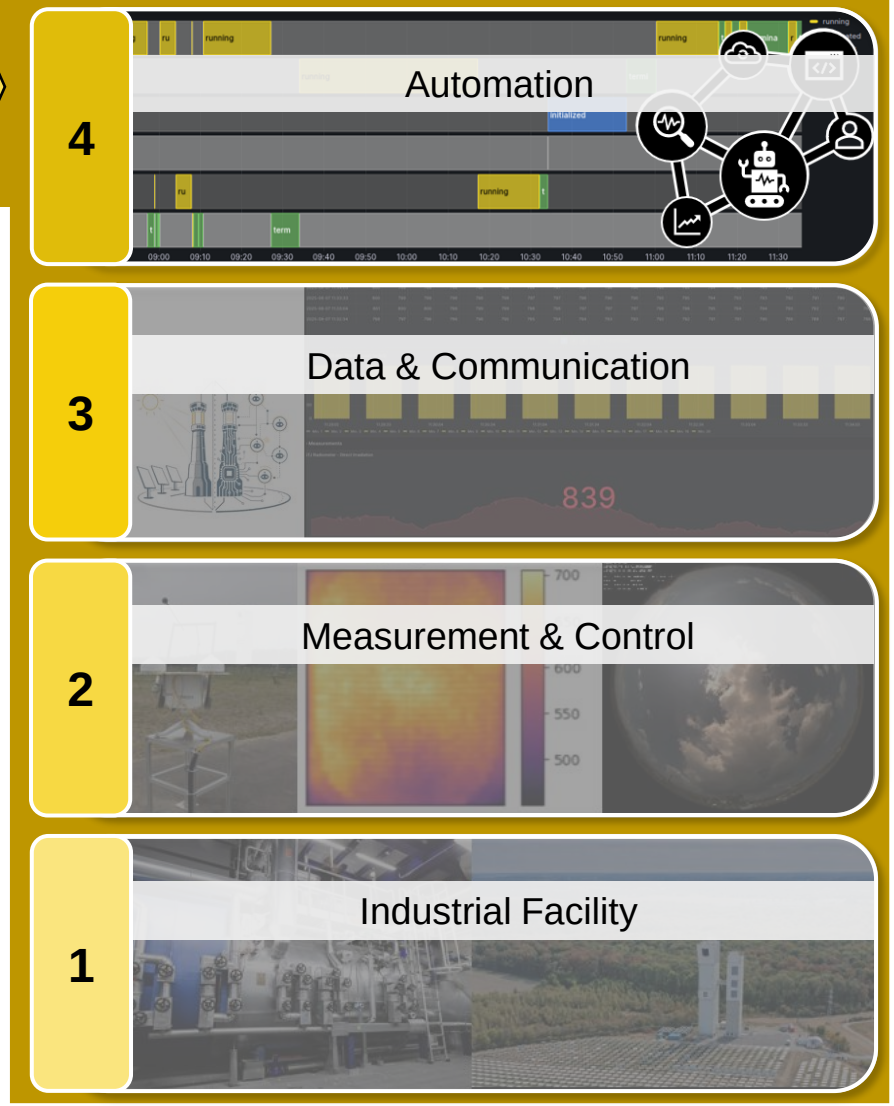


SOLEA Architecture
High-level overview of the holistic concept

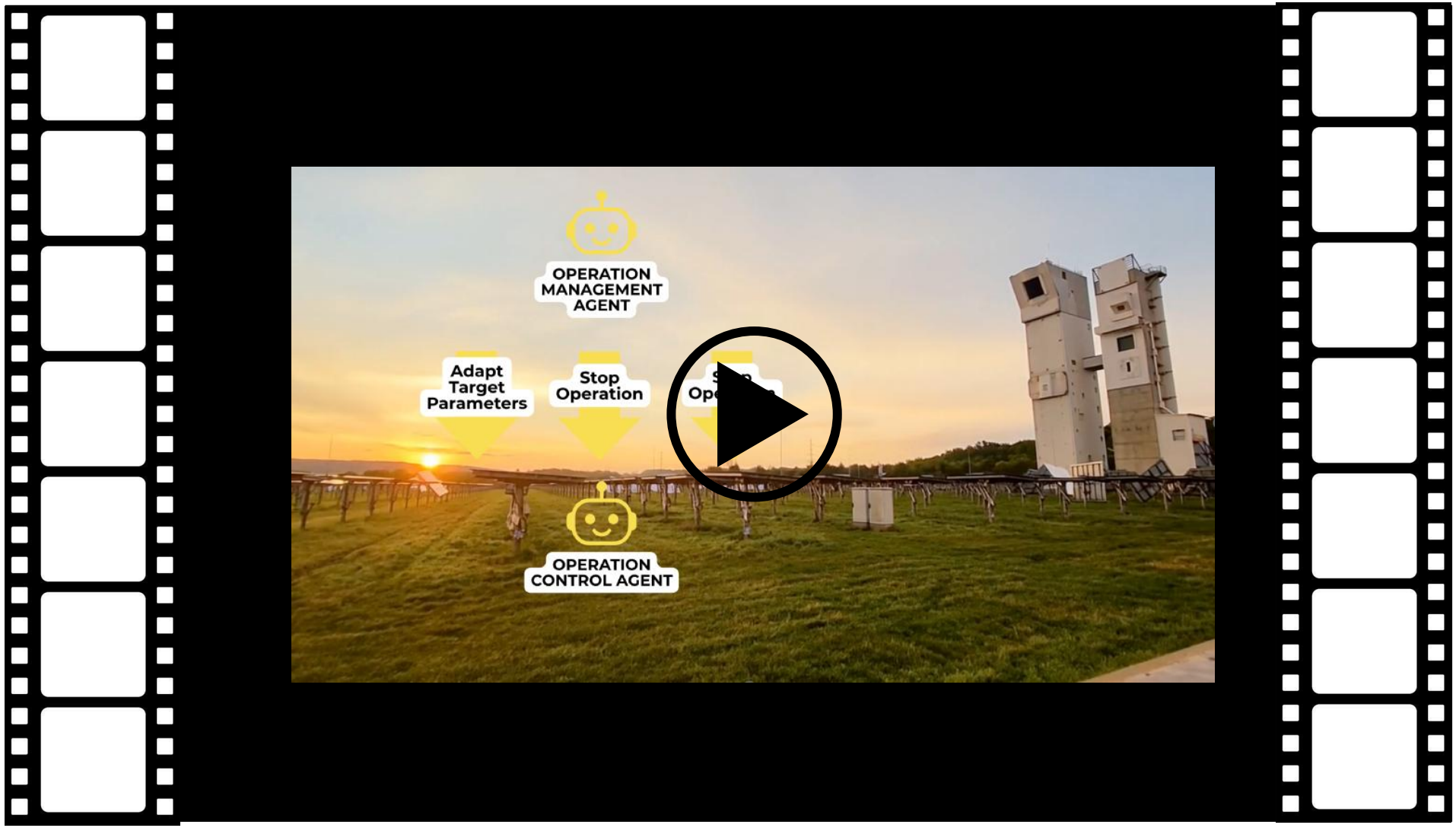
Solar **E**nergy **A**utopilot

4. **Automation:** Multi-Agenten System (MAS)
(Article: https://doi.org/10.3390/systems14010076)





SOLEA Demonstration
30-hour test campaign at the Solar Tower Jülich



Results & Conclusion

A modular architecture, demonstrated under real operating conditions

01 INTEGRATED

One plant-wide architecture

4 Automation
3 Data & Communication
2 Measurement & Control
1 Industrial Facility

Full stack integration from plant components to autonomous agents

02 DEMONSTRATED

End-to-end operation demonstrated



Agents executed the complete operating sequence under real plant conditions.

03 TRANSFERABLE

A reusable architecture blueprint

SOLEA

CST PLANTS | PROCESS HEAT | SOLAR FUELS | FURTHER SYSTEMS

Modular interfaces enable adaptation to further CST and industrial heat systems.

★ SOLEA closes the gap to plant-wide autonomy – and opens the path to CST as a standardized heat source

SOLEA - Solar Energy Autopilot
Where to learn more?



Oral Presentation – Digital Tools and AI – 16th September 16:15 – 16:30
Autonomous Operation Control Agent for Robust Solar Thermal Tower Plant Operation
mathias.kuhl@dlr.de



Oral Presentation – Digital Tools and AI – 16th September 16:30 – 16:45
Solar Energy Autopilot: A Digital Twin Framework for Autonomous Solar Thermal Plants
inga.miadowicz@dlr.de



Technical Tour – Solar Power Tower Jülich – 19th September 08:00 – 15:00
On-site insights on the Solar Energy Autopilot and Jülich Facility
daniel.maldonadoquinto@dlr.de

DLR Booth – 17th September 09:00 – 10:00
Meet Inga and Mathias at the DLR booth for questions, discussion and potential collaborations.



Thank you for your attention.

We are happy to answer additional Questions in person or via E-Mail

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References

[1] „*Solar Energy Autopilot (SOLEA): A Holistic System Architecture for Autonomous Concentrated Solar Thermal Plants and Its Evaluation in an Operational Power Tower Facility*“ - Miadowicz, I., Kuhl, M., Maldonado Quinto, D., Dürr, N., Schwarzbözl, P., Sibum, M., ... & Pitz-Paal, R., Felderer, M.; Pre-Print submitted to Solar Energy (2026). https://dx.doi.org/10.2139/ssrn.5788942

[2] „*From Automation to Autonomy: A Digital Twin Framework for Transparent Agent and Human Collaboration in Industrial Multi-Agent Systems*“ - Miadowicz, I., Kuhl, M., Maldonado Quinto, D., Pitz-Paal, R., & Felderer, M. (2026). Systems, 14(1), 76. https://doi.org/10.3390/systems14010076

[3] „*Digital Twin in manufacturing: A categorical literature review and classification*” - Kritzinger, W., Karner, M., Traar, G., Henjes, J., Sihn, W (2018). IFAC-PapersOnLine, 51, 1016–1022. https://doi.org/10.1016/j.ifacol.2018.08.474

[4] “*An action research study on the digital transformation of concentrated solar thermal plants*” - Miadowicz, I., Quinto, D. M., Pitz-Paal, R., & Felderer, M. (2025). Solar Energy Advances, 5, 100102. https://doi.org/10.1016/j.seja.2025.100102