Economic views on solar power

- Recap and update on SolarPACES 2025 conference contributions

January HelioCon Seminar I

Axel Schweitzer, sbp sonne gmbh
Thomas Keck, Alf Oschatz and Fabian Gross, sbp sonne gmbh
Dengke Sun, DEC Boiler
Xie Zhao, CSNP

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SolarPACES
Concentrating Solar Power, Thermal, and Chemical Energy Systems

September 23-26, 2025
Almería, Spain
31st SolarPACES Conference

Part I: Cost reduction through learning curve effects at CSP power plants in China

Part II: Solar collectors for 500+°C process heat

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Part I: Cost reduction through learning curve effects at CSP power plants in China

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CSP implementation policies in China:

Phase	Time period	Tariff	Condition
I	Starting 2014	Special fixed FIT for CSP (higher than normal FIT)	CSP with TES (1st and 2nd batch CSP demonstration plants)
II	Starting 2020	Normal fixed FIT	Mandatory for large PV/Wind projects to include share of CSP with TES
III	Starting 2025 Not yet implemented by all provinces	Market based pricing Possibility to sell: • electricity on spot market • firm guanteed power capacity • ancilliary services (ramping, frequency/ voltage regulation etc.)	„Document 136“ No conditions to system configuration

Chances

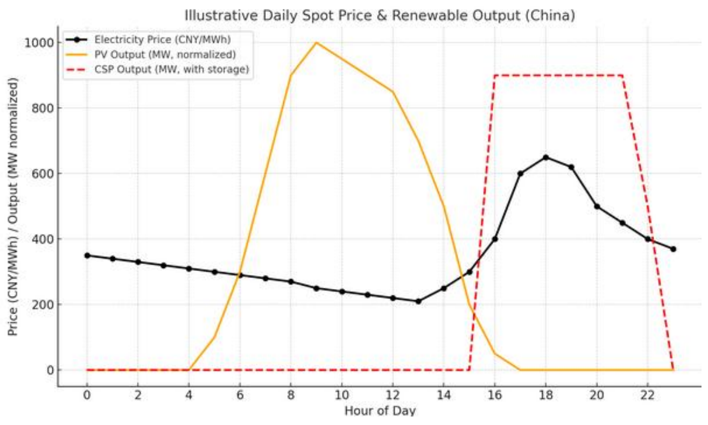
Chances
Dispatchable CSP: 4-12h storage fits peak / firm capacity needs
CSP captures scarcity price premiums in evening peaks
CSP is eligible for capacity/ancillary market revenues

Challenges

Revenue uncertainty during policy transition (financial models and risk management change completely)

Competition on the same markets segments from e.g.:

- Grid connected BESS
- Pumped hydro
- Short term: coal plants



Summary

- CSP is assumed to have reached full market competitiveness without need of further subsidies
- „Document 136“ provides chances that fit to CSP, but increases competition among technologies

Chances

Dispatchable CSP: 4-12h storage fits peak / firm capacity needs

CSP captures scarcity price premiums in evening peaks

CSP is eligible for capacity/ancillary market revenues

Challenges

Revenue uncertainty during policy transition (financial models and risk management change completely)

Competition on the same markets segments from e.g.:
- Grid connected BESS
- Pumped hydro
- Short term: coal plants

Update 01’26 for the five provinces with the highest potential:

Qinghai, Xinjiang, Gansu, Inner Mongolia, Tibet

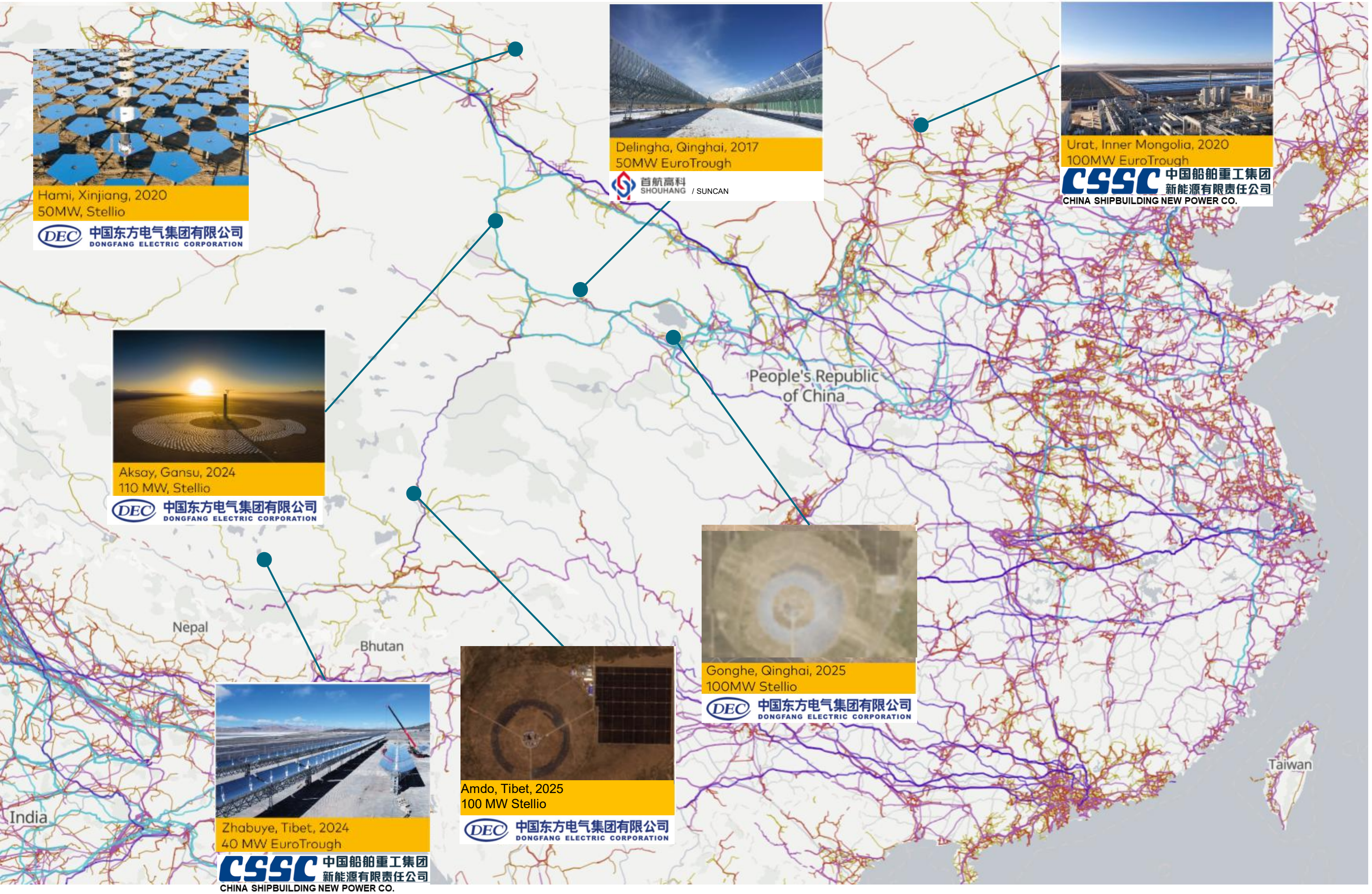
All provinces have started implementation, but spot markets are not fully functional so far.

Transitional measures are implemented to avoid discontinuity of CSP development.

E.g.: Qinghai has implemented FIT of 0.55 RMB/kWh (0.08$/kWh) until 2028

Summary

- CSP is assumed to have reached full market competitiveness without need of further subsidies
- „Document 136“ provides chances that fit to CSP, but increases competition among technologies



Continuous development with industrial partners to benefit from a learning curve to improve performance and reduce cost [1,2]

[1]CSP projects with sbp collector design
[2] Power lines https://openinframap.org

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EuroTrough learning curve CSNP/sbp

sbp scope

- Engineering
- License
- Training
- Quality control
- Design improvement

Project Name	Completion	Country	Collector	Configuration
Zhabuye	2024	China	ET	621,000 m²
Urat	2019	China	ET	1,151,000 m²
Rotem 1	2018	Israel	ET	20,000 m²
Delingha	2017	China	ET	625,000 m²
Shagaya	2017	Kuwait	ET	674,000 m²
Cargo, Gujarat	2013	India	ET	327,000 m²
Godawari GGEL Solar Plant	2013	India	ET	392,000 m²
Extremasol	2012	Spain	ET	533,000 m²
Morón	2012	Spain	ET	380,000 m²
Astexol	2012	Spain	ET	510,000 m²
Solar Combined Power Plant Kuraymat	2011	Egypt	ET	131,000 m²
Andasol I, II, III	2008 - 2011	Spain	ET	3 x 510,000 m²

sbp scope

- Engineering
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Long-term Technology partner

(non-exclusive)

中国船舶重工集团 新能源有限责任公司
CHINA SHIPBUILDING NEW POWER CO.

- Supply chain optimization
- Fabrication optimization
- Assembly and erection optimization

→ Joint engineering, procurement & construction learning curve

Project Name	Completion	Country	Collector	Configuration
Current bidding processes	2026	China	ET	nn
Zhabuye	2024	China	ET	621,000 m²
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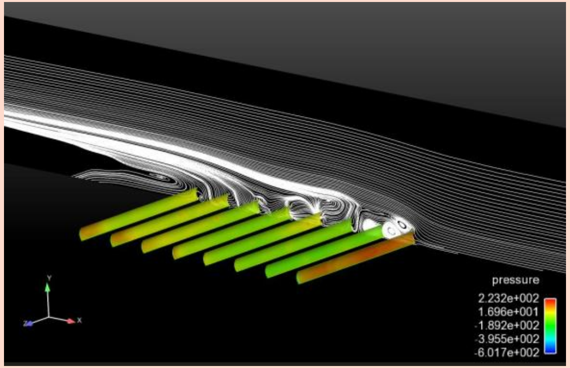
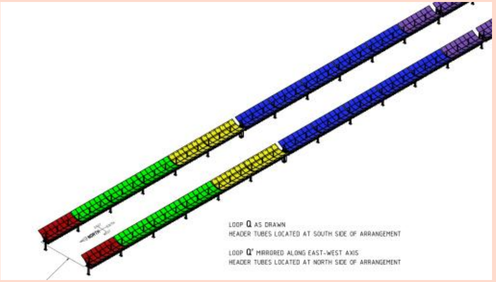
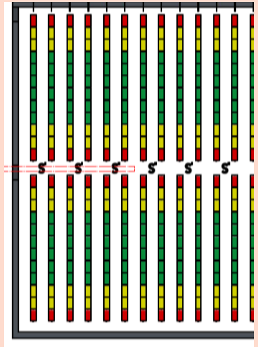
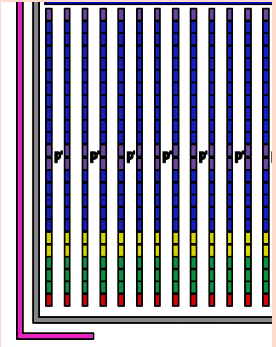
<table>
<tr><th>Improvement</th><th>Impact</th></tr>
<tr><td>Design:
Solar field configuration optimized by wind tunnel tests (sbp) and fluid dynamic simulation (CSNP)

</td><td>Optimized distribution of components in the solar field (regular, reinforced elements)
→ Total mass reduction


→ Improved manufacturing & assembly
→ Steel cost reduction approx. 5.7%</td></tr>
<tr><td>Localization of supply chain of
• material & fabrication (Chinese Standards)
• key components
• optimized procurement management</td><td>→ Cost reduction distributed over the projects
→ See summary chart</td></tr>
</table>

Improvement	Impact
Erection & Assembly: Optimized assembly procedures to increase output  **Optimization of quality:** • Strict quality control • Reduction of rework • Stable geometric accuracy	• Output of Zhabuye assembly line more than doubled • Peak output approx. 5 Solar Collector Assemblies per day (240 Solar Collector Elements) = 2 soccer fields of aperture / day • Collector intercept stable > 97% → Installation cost reduction approx. 8.5 %

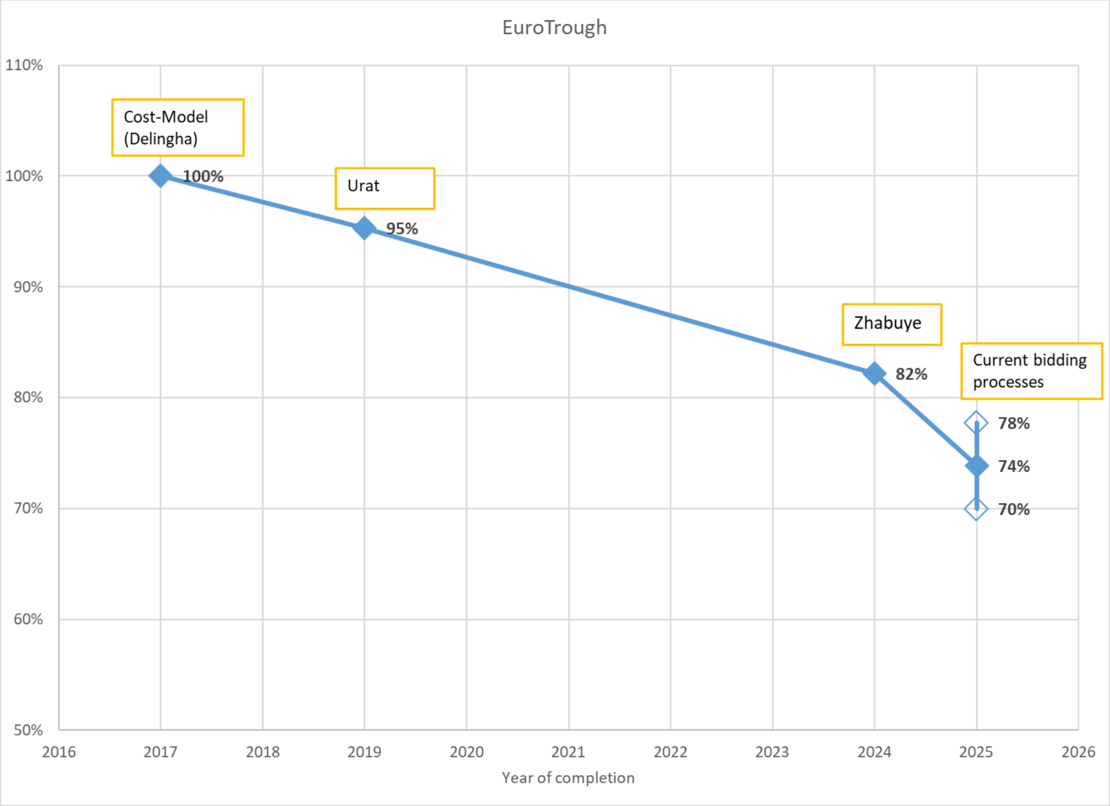
Improvement	Impact
Design: • EuroTrough installation on sloped solar  → Solar field of Delingha installed on multiple terraces with large terrain steps → Possibility to install EuroTrough on up to 3% sloped ground	 →  Delingha → Zhabuye → Avoiding terraces leads to • Less efforts in Earthworks • Unification of Solar field (Collectors / HTF system etc.) → Cost reduction approx. 3 – 6 %

Development of solar field investment cost *

Base of comparison:

- Including solar field with HTF system and foundations
- Earthworks excluded
- Equal site + wind load conditions
- Large size of solar field (500,000 m²)

** Based on CSNP data and bidding results*



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EuroTrough learning curve CSNP/sbp

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Stellio learning curve DEC/sbp

Project Name	Completion	Country	Collector	Configuration
Amdo	2026	China, Tibet	Stellio	800,000 m²
Gonghe	2025	China, Qinghai	Stellio	500,000 m²
Aksay	2024	China, Gansu	Stellio	580,000 m²
Hami	2020	China, Xinjiang	Stellio	703,000 m²

sbp scope

- Engineering
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Long-term Technology partner

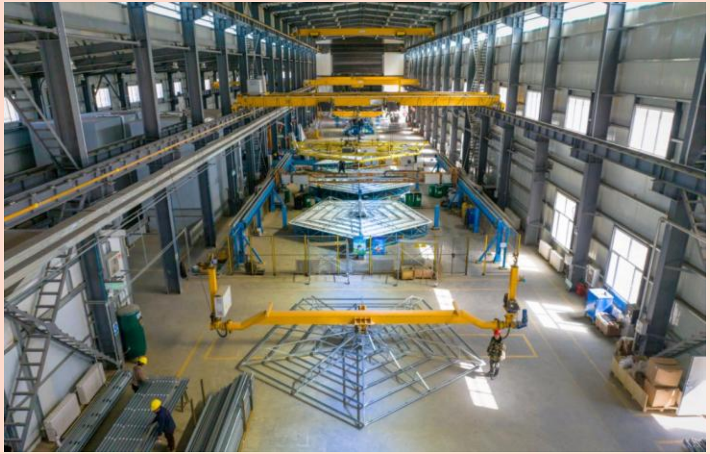
(non-exclusive)

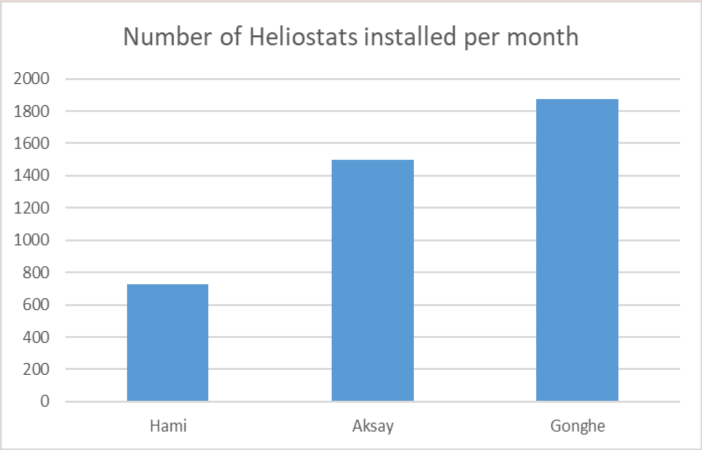
DEC 中国东方电气集团有限公司 DONGFANG ELECTRIC CORPORATION

- Supply chain optimization
- Fabrication optimization
- Assembly and erection optimization

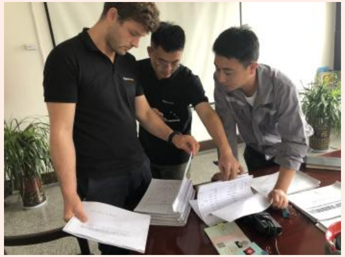
→ Joint engineering, procurement & construction learning curve

Improvement	Impact
Optimization of fabrication, assembly and erection procedures to increase output	Output of assembly line more than doubled





Component	Improvement	Impact
Support arm and lug plates	Welded + hot dip galvanized profiles → pre-coated ZAM profiles, laser-cutting + laser-welding Additional cold-zinc treatment to welds	→ More demanding fabrication process, but significant cost reduction → Increased slip resistance for bolted connections
Pin axle	NiCr electroplating replaced by QPQ (Quench-Polish-Quench) treatment	→ Reduced cost → Sufficient corrosion resistance

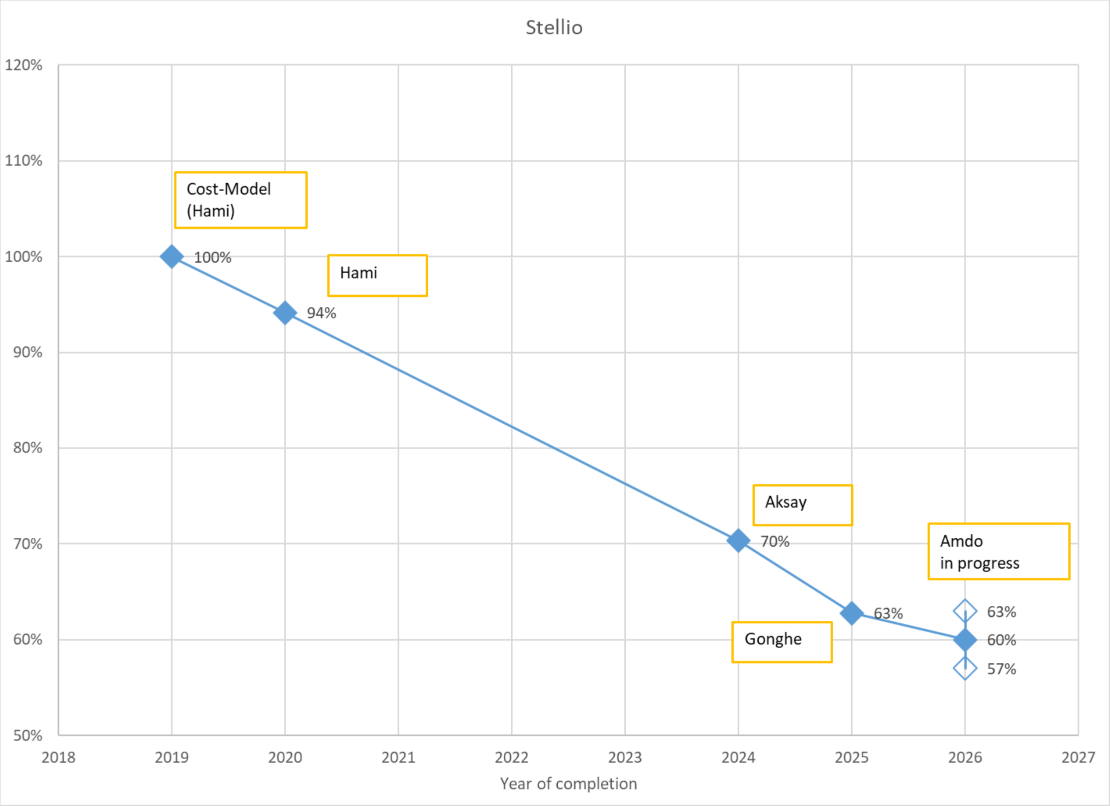
Component	Improvement	Impact
Glue	Glue with thermal curing replaced by new glue type	→ Improves assembly efficiency and time → More stable bonding quality
Engineering supervision (sbp)	Review of fabrication procedures from design perspective to verify lessons learnt 	→ Maintain Stellio optical and mechanical performance requirements
		→ Total metal support structure cost reduction approx. 50 %

Development of solar field investment cost *

Base of comparison:

- Including solar field and foundations
- Earthworks excluded
- Equal site + wind load conditions
- Large size of solar field (500,000 - 1,000,000 m²)

** Based on DEC data*



Conclusion

CSP is assumed to have reached full market competitiveness without need of subsidiaries :

- Document 136 sets completely new boundary conditions for financial models and plant configurations.
- „Document 136“ provides chances that fit to CSP, but increases competition among technologies.

EuroTrough and Stellio technologies by sbp can compete in the market as they profit from continuous industrial partnerships:

DONGFANG ELECTRIC CORPORATION

CHINA SHIPBUILDING NEW POWER CO.

- EuroTrough was already a mature technology when entering in the Chinese market. With learning curve implemented together with CSNP a cost reduction to 74% was realized.
- Stellio had the first commercial application in China. Together with DEC an even steeper learning curve to 60% was realized.

Acknowledgements

We would like to thank our partners for their support and assistance in preparing this presentation:

Xie Zhao

China Shipbuilding New Power Co., Ltd. (CSNP), China

CSSC 中国船舶重工集团新能源有限责任公司
CHINA SHIPBUILDING NEW POWER CO.

Dengke Sun

Dongfang Boiler Group Co., Ltd. (DEC Boiler), China

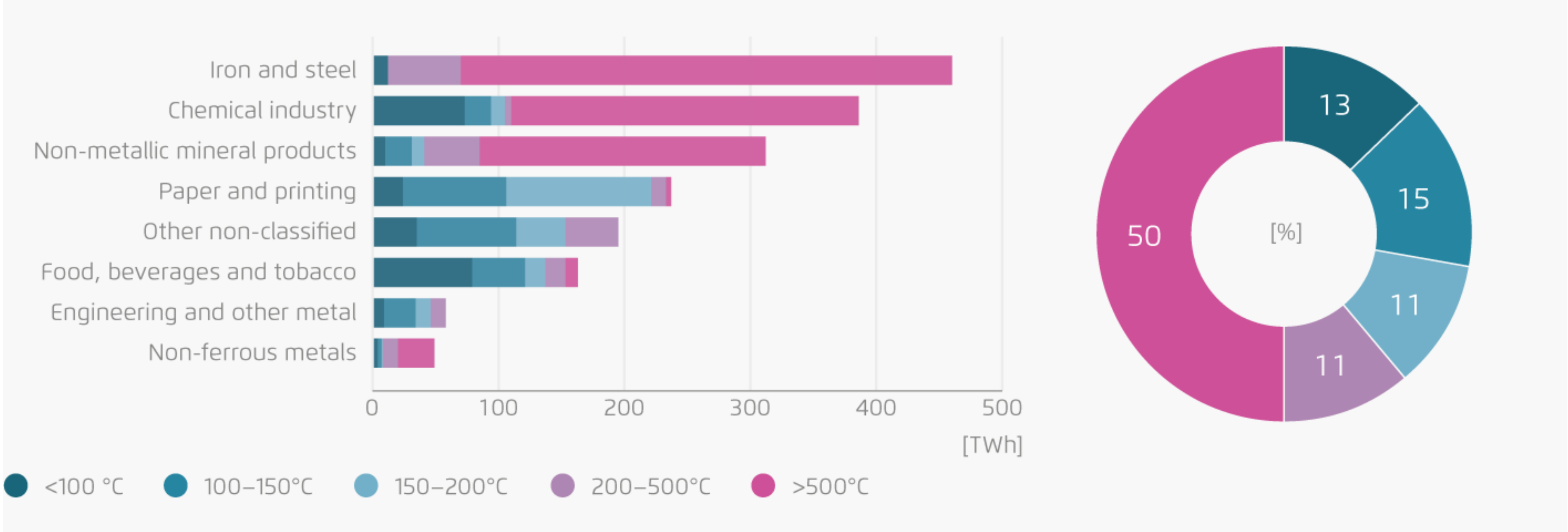
DEC 中国东方电气集团有限公司
DONGFANG ELECTRIC CORPORATION

Part II Solar collectors for 500+°C process heat

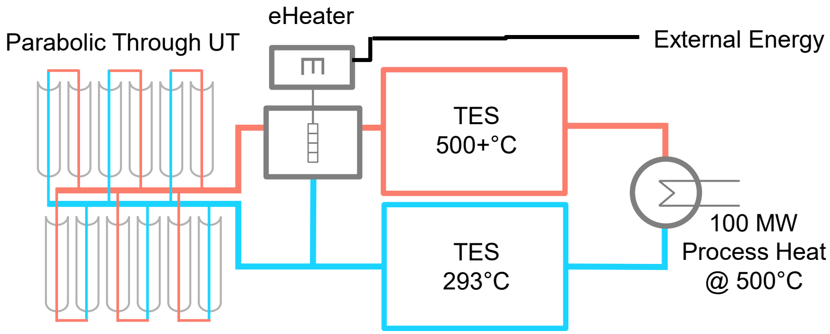
Axel Schweitzer, Fabian Gross, Alf Oschatz, sbp sonne gmbh

Estimated total final energy demand for process heating in 2019 by temperature and energy carrier in the EU-27 countries

→ Fig. 5



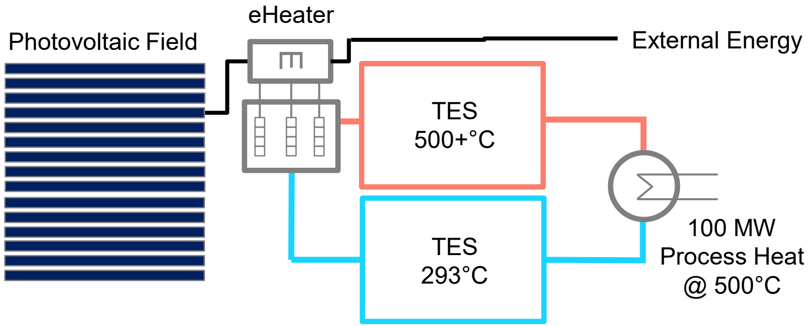
https://www.agora-industry.org/publications/direct-electrification-of-industrial-process-heat



Boundary Conditions

Ultimate Trough + TES and
Single-axis PV-Tracker + TES

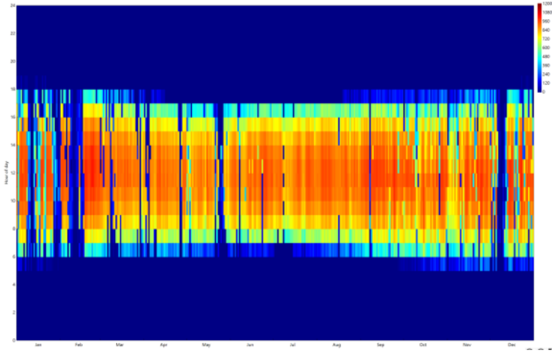
Nominal Thermal Power	100 MW_{th} from renewables
Nominal Temperature	500+ °C
Capacity Factor (including Hybridization)	100 %
Solar Field and TES Size	Economic optimum
Hybridization	Purchased external electricity for E-heater (from renewable resources)

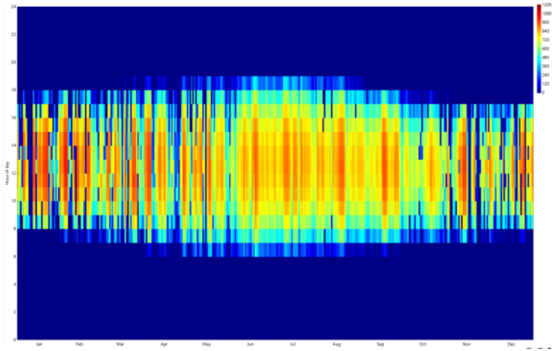


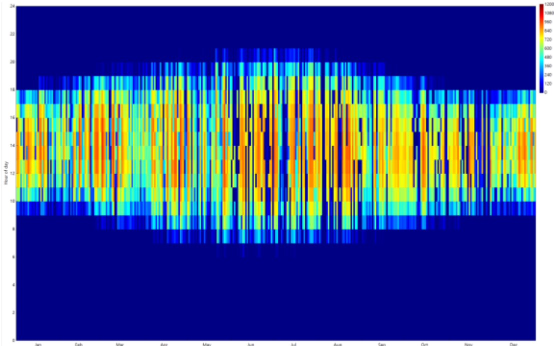
Main Specific Cost Assumptions

CSP	[M€ / km²]	150 – 200
PV	[M€ / MW_{ac}]	0.46 – 0.7
eHeater	[M€ / MW]	0.07
TES	[M€ / MWh]	0.016
External Energy Price	[€ / MWh]	100
Sales Price To The Grid	[€ / MWh]	20
Electric Power Capacity	[M€ / MW / a]	0.05

	Lat	Lon	DNI	GHI	CSP	PV
	°	°	MWh/m²		€/m²	€/W_AC
AUS	-20	123.0	2.7	2.3	200 +- 20	0.70 +- 0.1
KSA	30	41.5	2.3	2.3	180 +- 20	0.70 +- 0.1
CN	40	94.4	2.0	1.9	150 +- 20	0.45 +- 0.1



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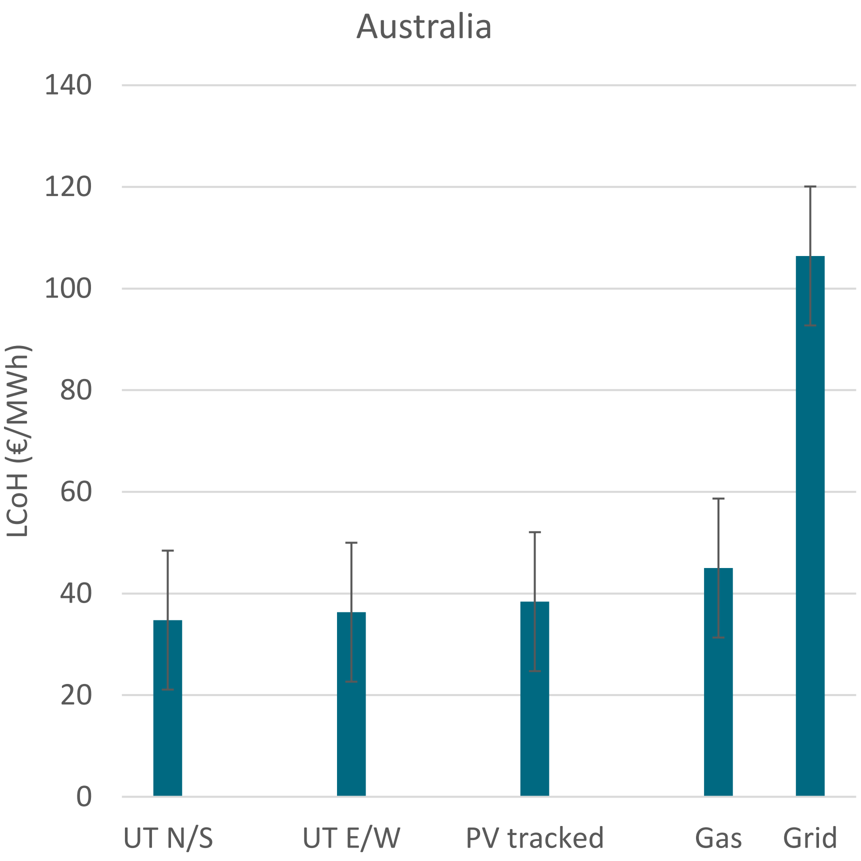
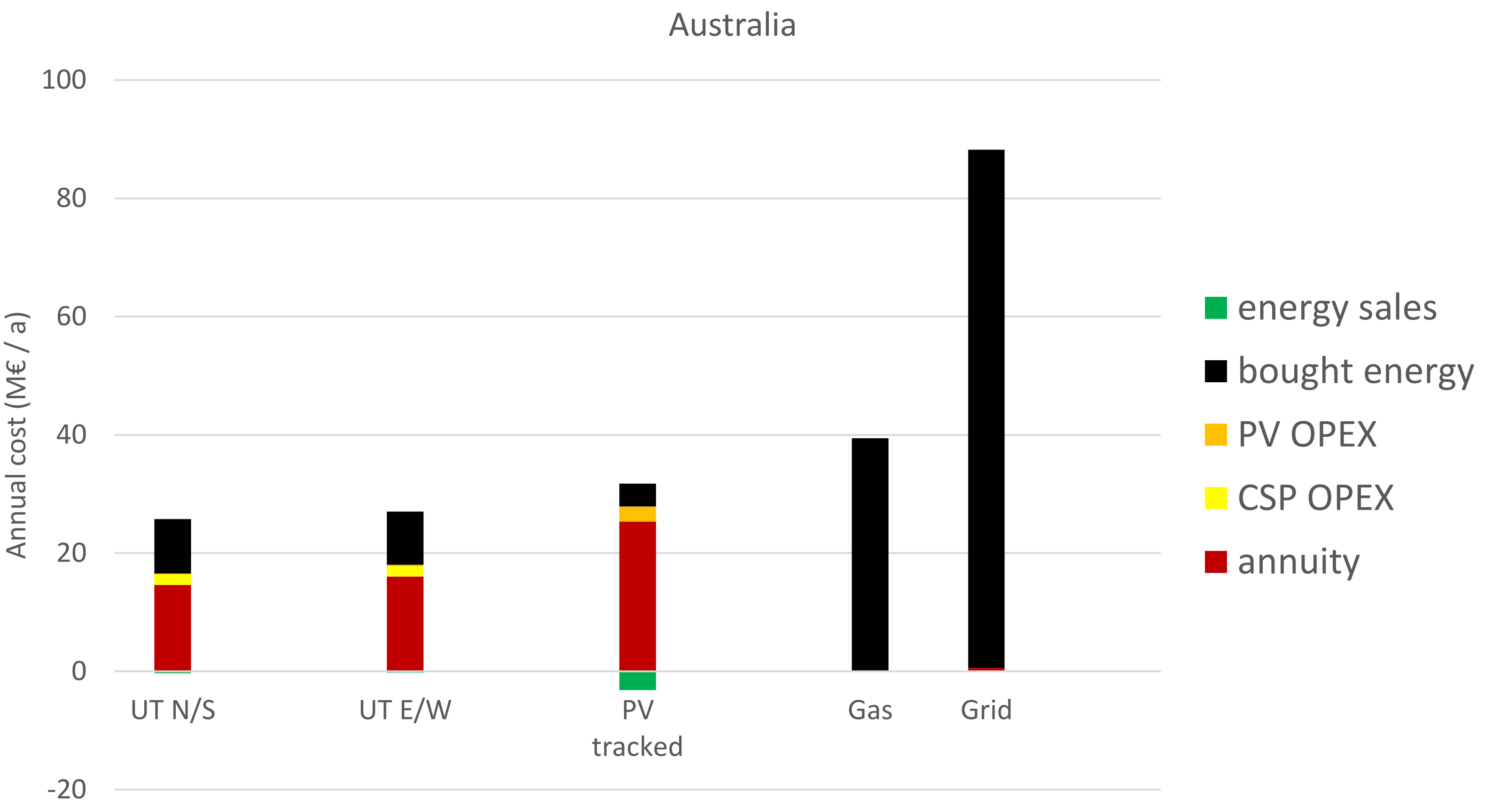
Sites & assumptions



		N/S	E/W	PV
Trough	km²	0.6	0.6	0
PV	MW_{ac}	20	30	360
Storage	h	18	24	15
Solar share	%	90	90	96
CAPEX	M€	170	186	295



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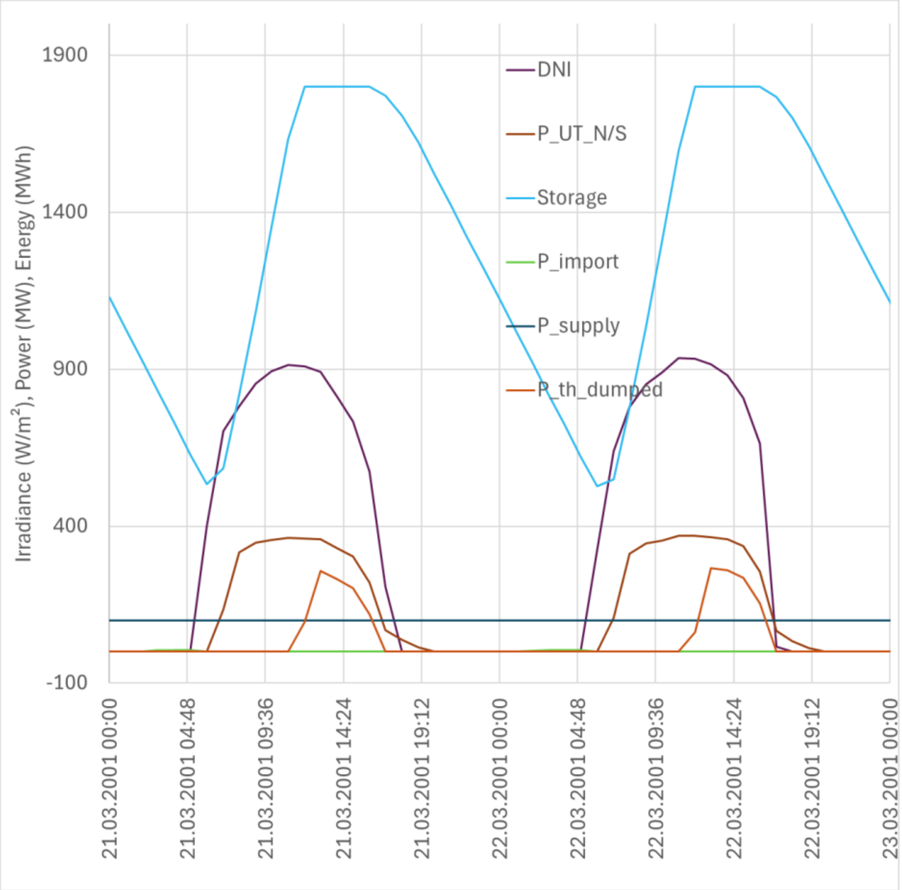
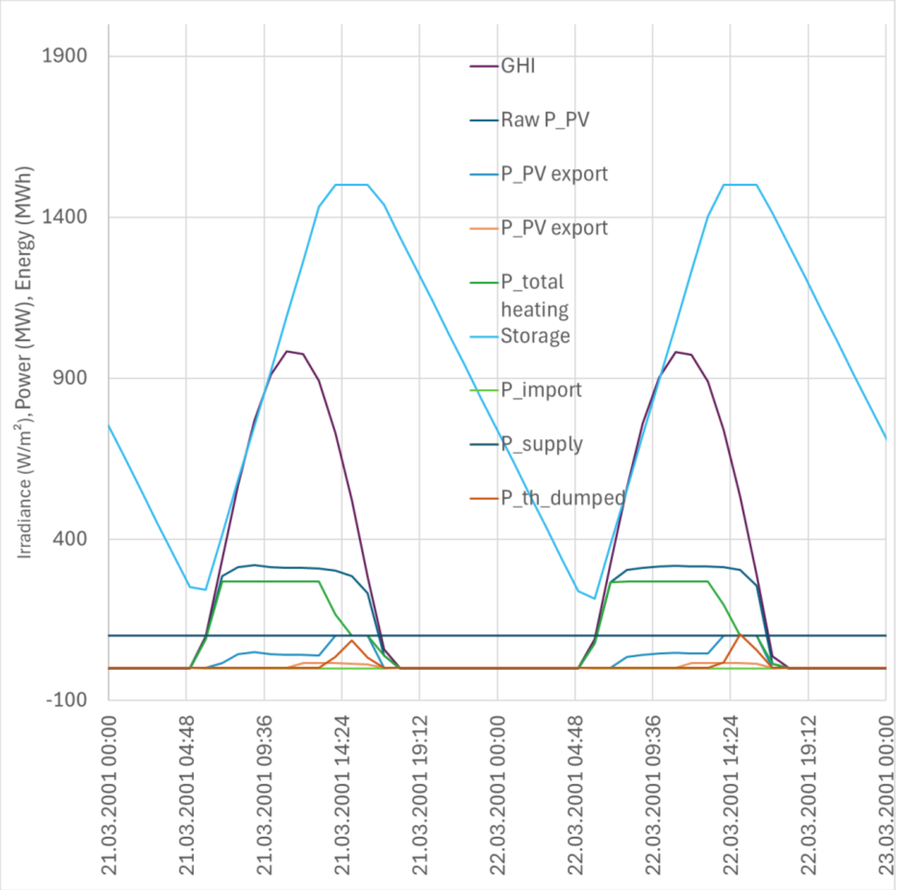
Where the money goes





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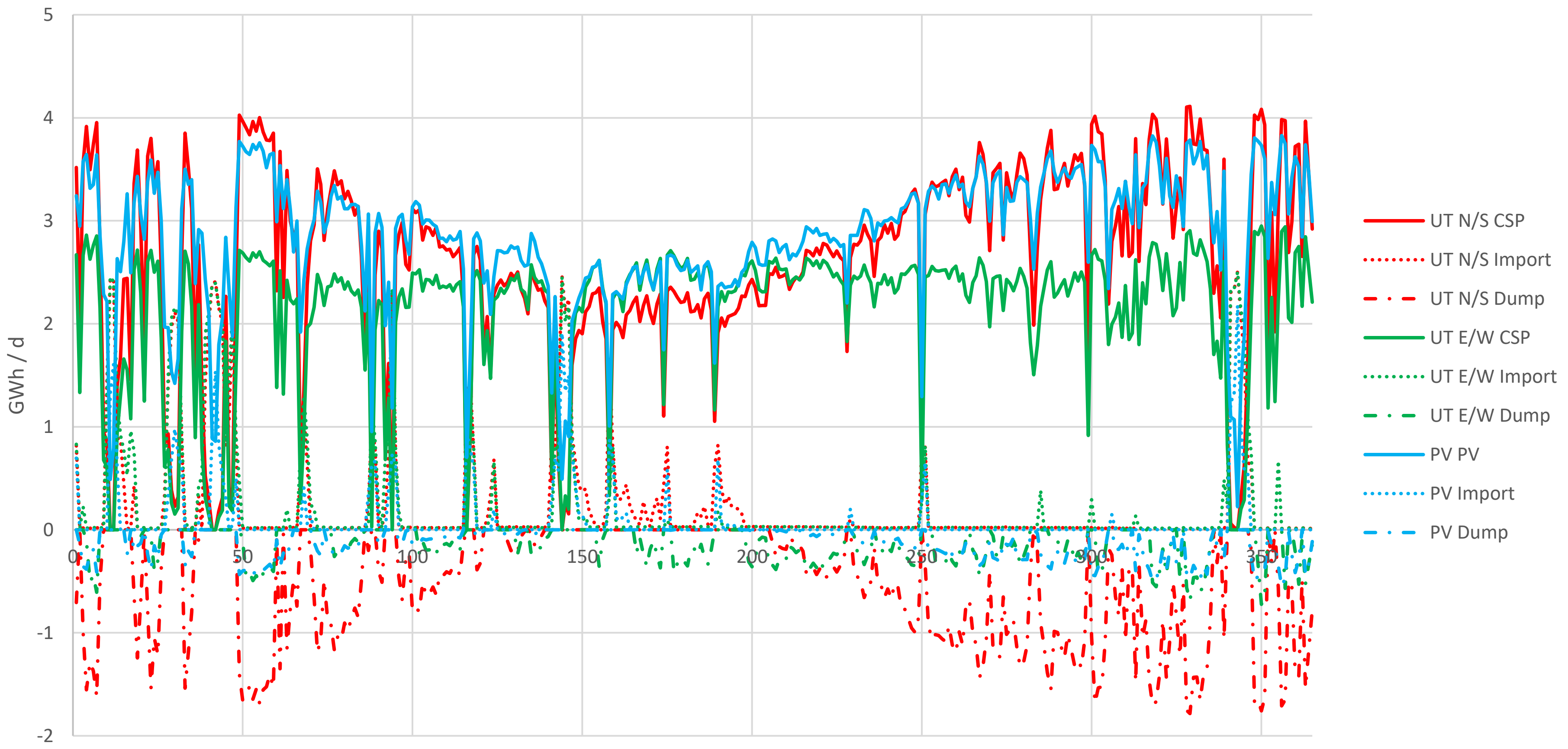
CSP and PV production at equinox



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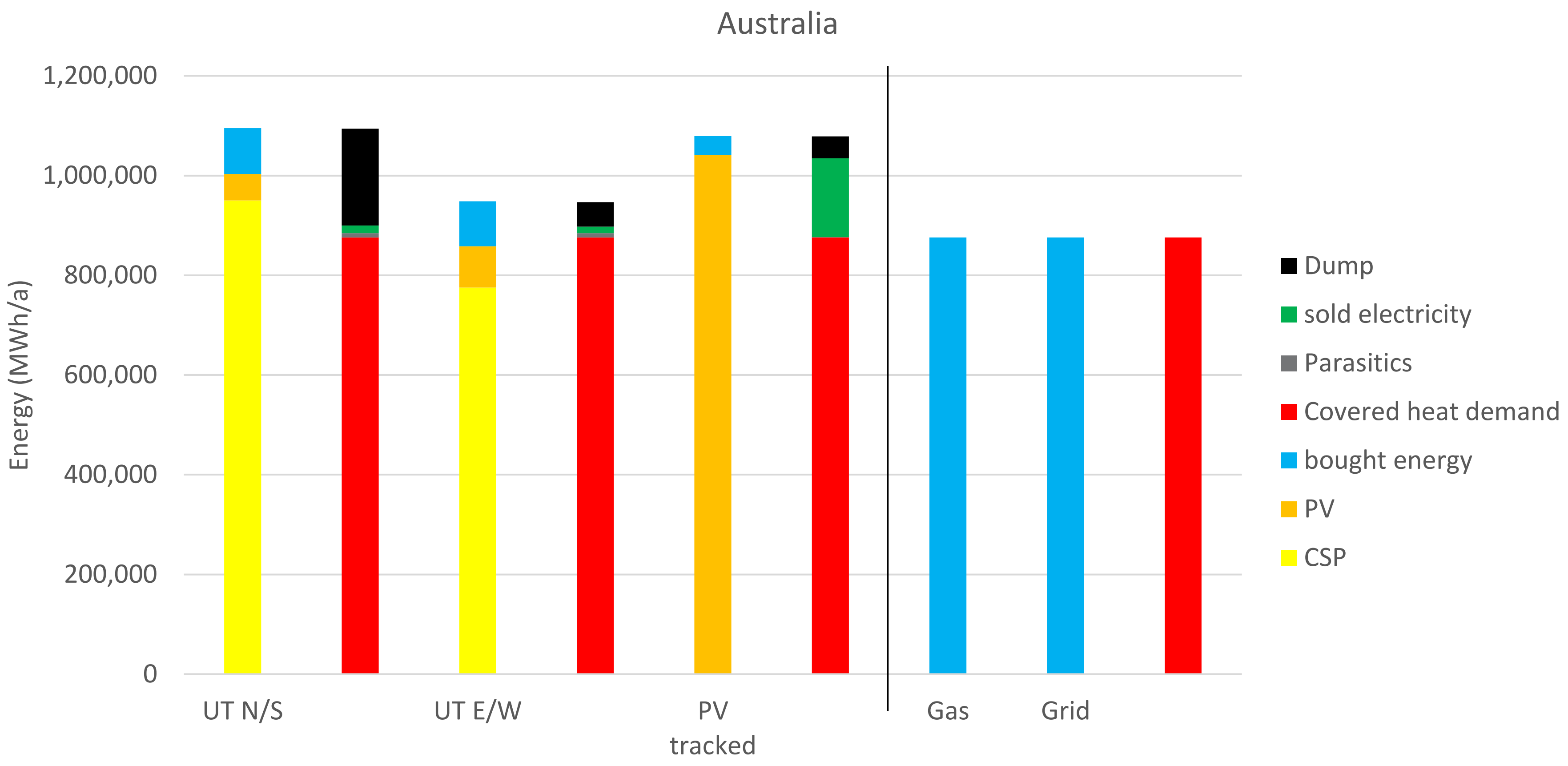
Australia: Annual performance



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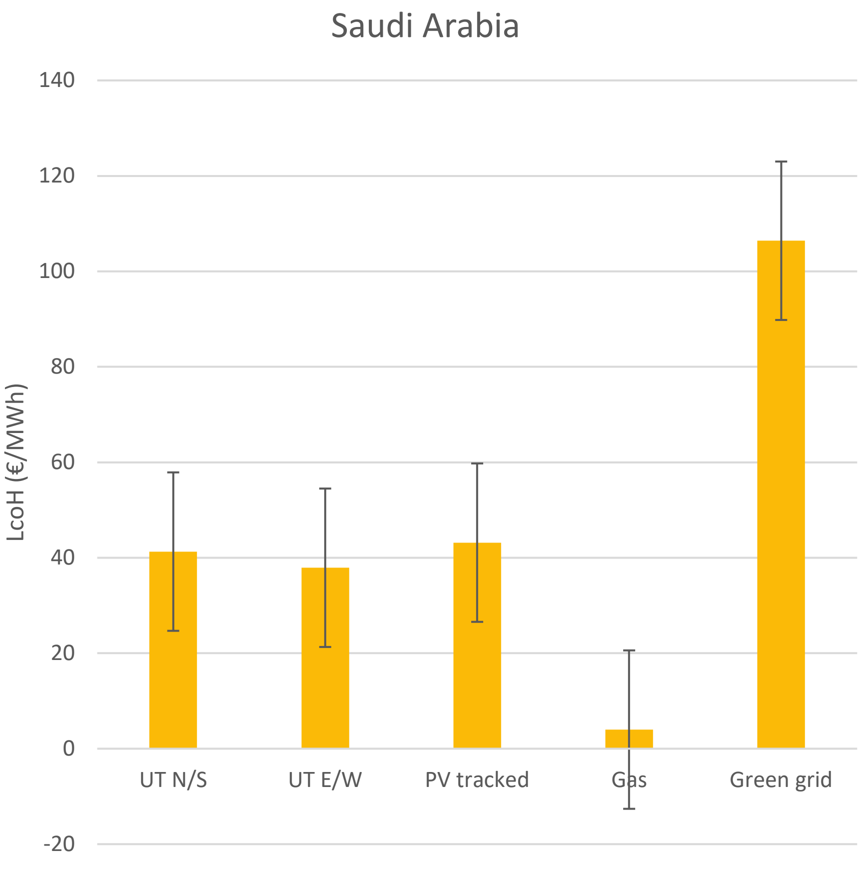
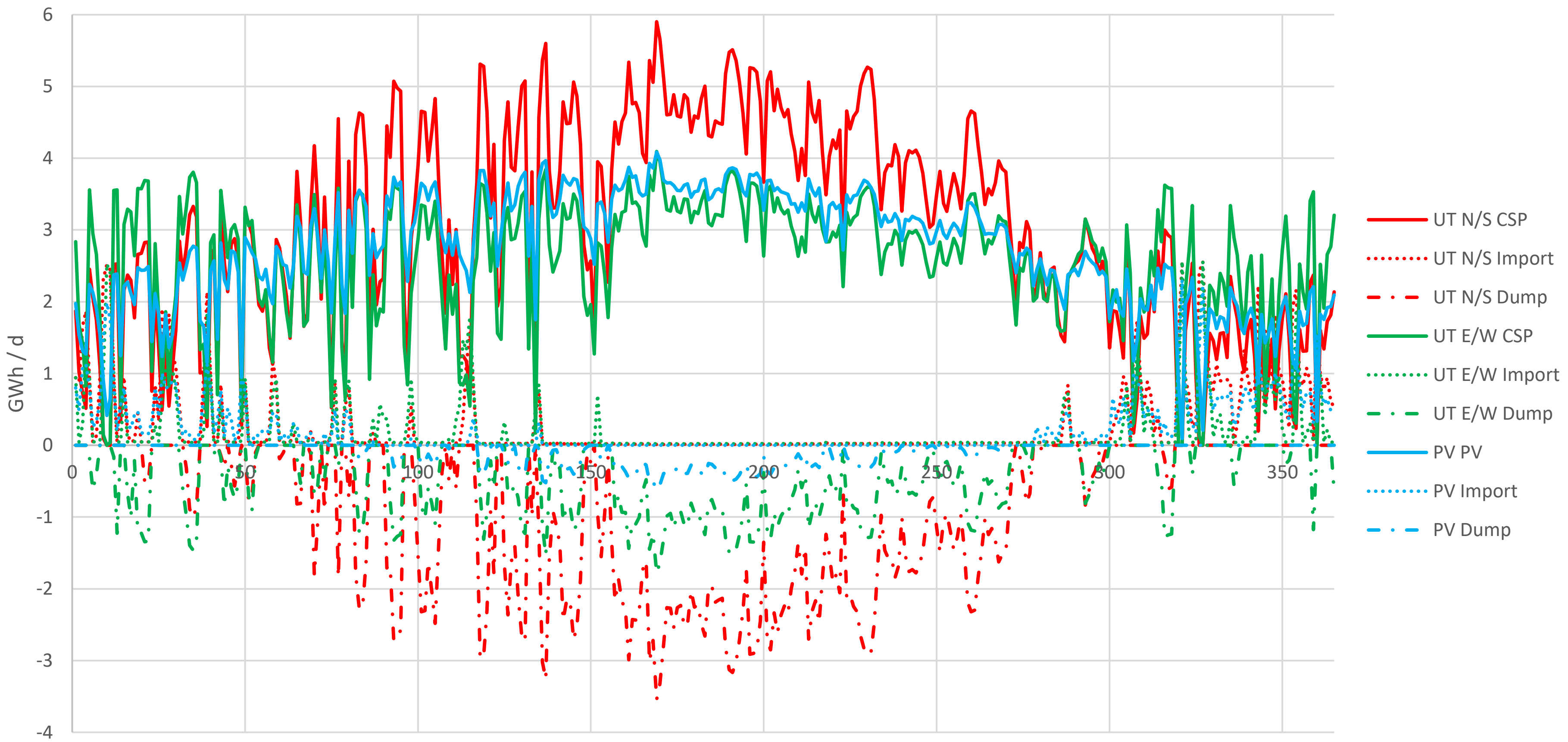
Distribution of energy sources and usage



		N/S	E/W	PV
Trough	km²	0.85	0.85	0
PV	MW_{ac}	20	20	360
Storage	h	22	25	15
Solar share	%	87	91	90
CAPEX	M€	209	214	294



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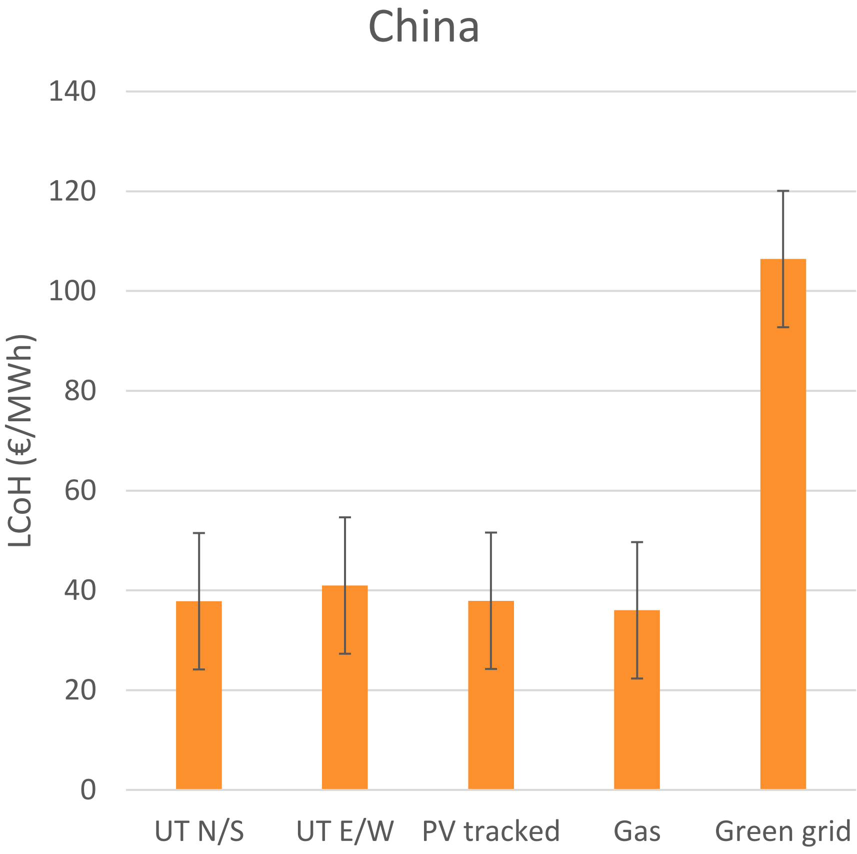
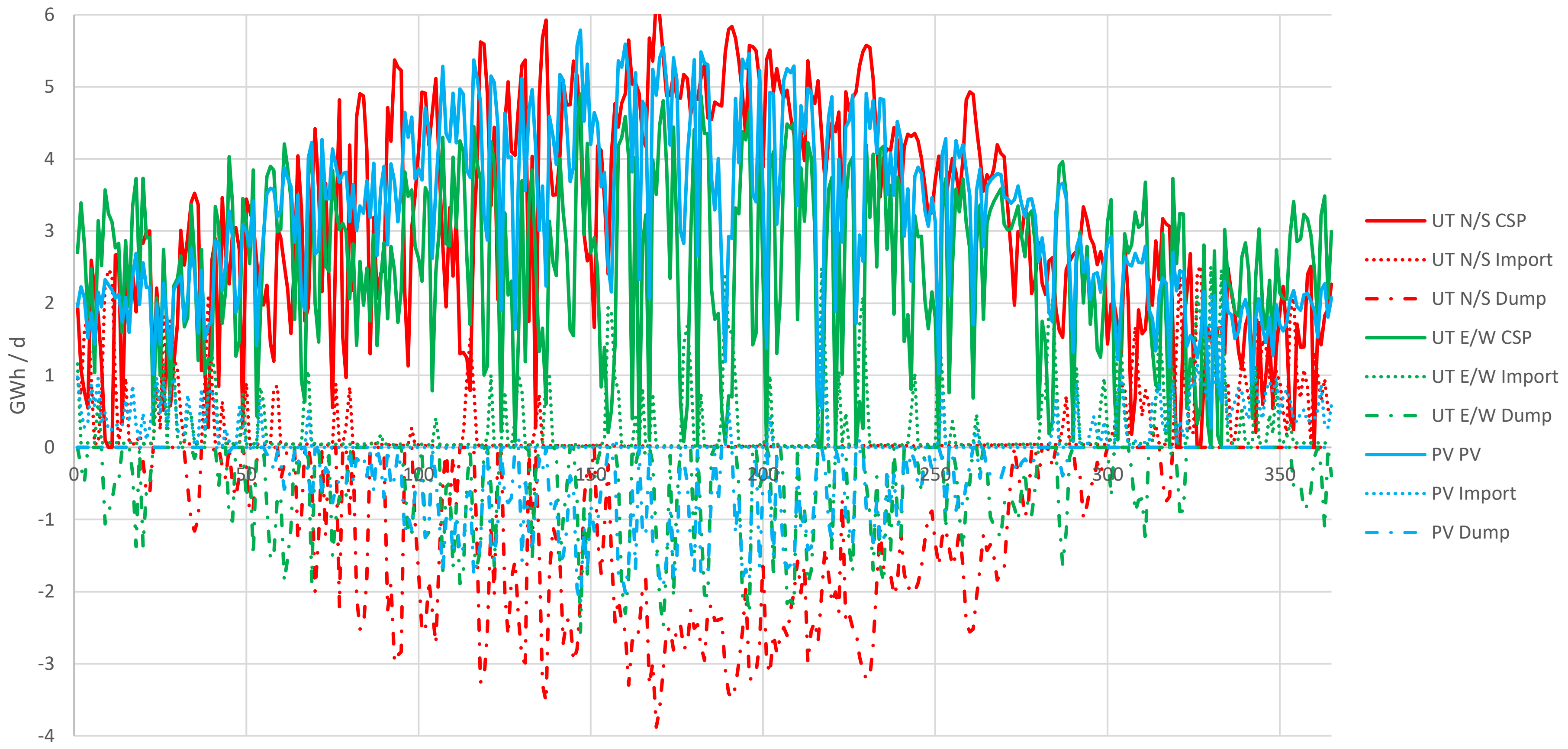
Saudi Arabia: Annual performance



		N/S	E/W	PV
Trough	km²	0.9	1.0	0
PV	MW_{ac}	20	20	490
Storage	h	22	27	18
Solar share	%	88	88	92
CAPEX	M€	186	209	269



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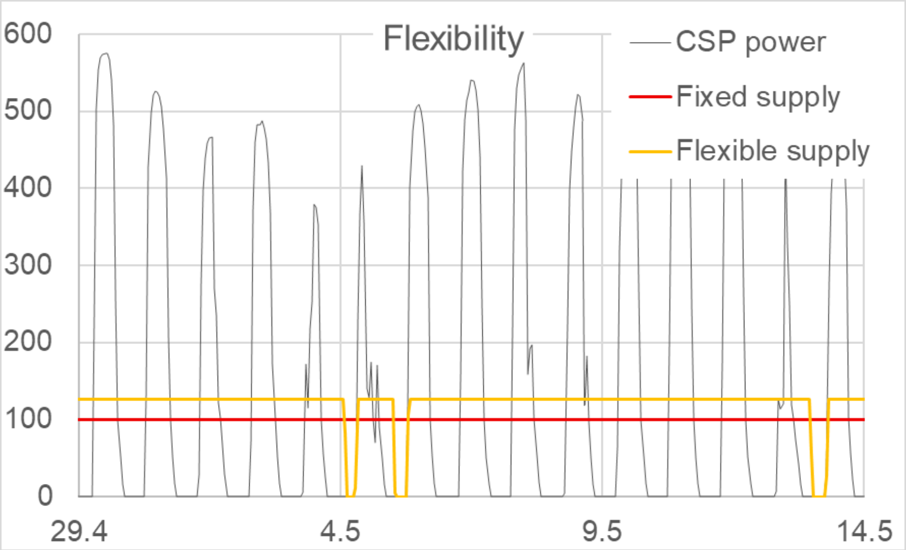
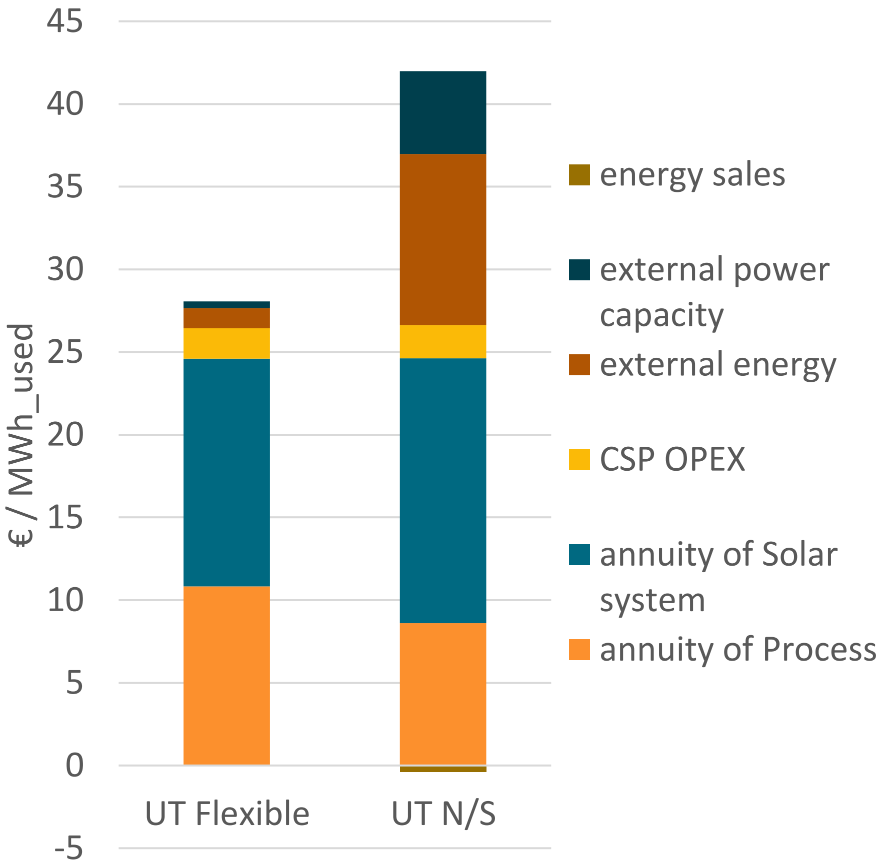
China: annual performance





Flexible supply to priced process

CST (trough or heliostat) and PV + Storage

= large heat demand with huge solar share

Grid connection => PV sells rather than dumps electricity

Flexibility reduces cost

Local effects

- Required temperature
- Cost structure
- Weather
- Supply chains
- CO_2 regulation

Solar process heat is economically viable in many countries:

- Solar is cheaper than buying green electricity
- Solar can often compete with gas (+ burner + infrastructure)
- CSP and PV have similar LCoH for this scenario

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CSP and PV + Storage + grid = clean, affordable 500+°C process heat

Thank you for your attention!

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Concentrating Solar Power (CSP)