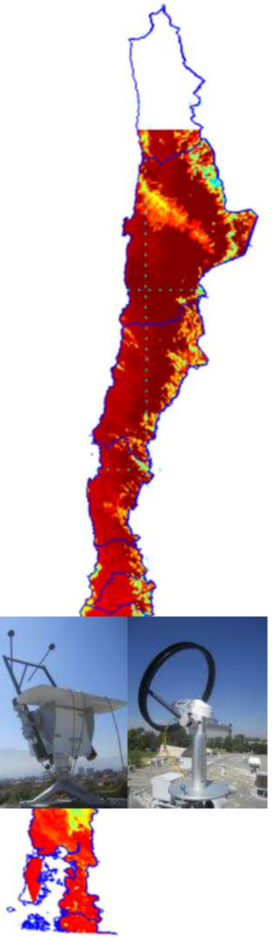
Seminario CSET – PUC

Plantas Híbridas CSP+TES+PV+BES



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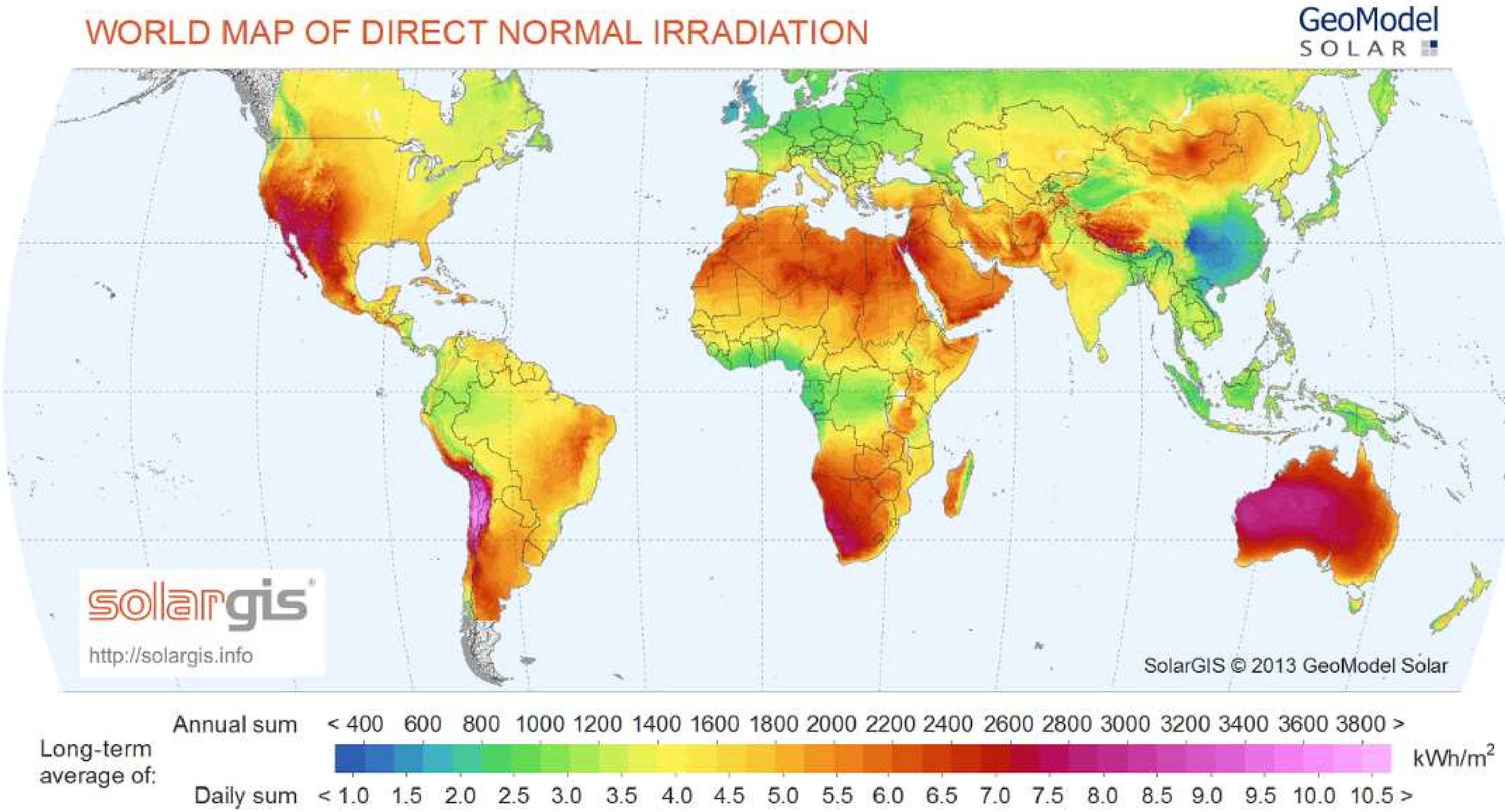
Contenidos

- Situación en Chile
- ¿Pueden CSP y PV satisfacer la demanda por separado?
- Análisis Técno-Económico Plantas híbridas CSP+TES+PV+BES

Situación en Chile

Chile en el mundo

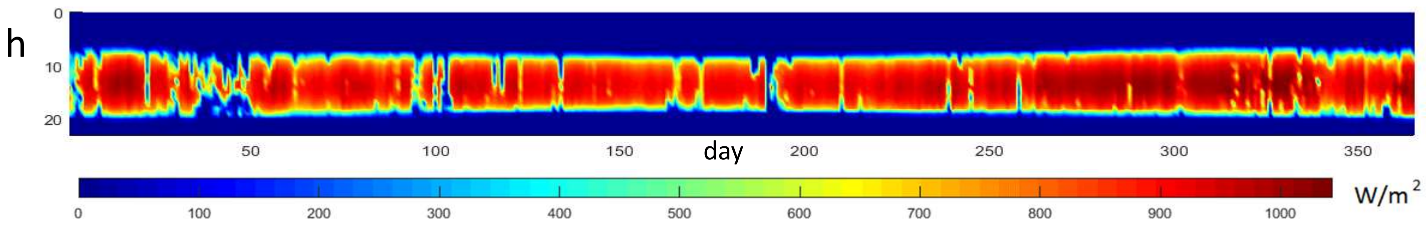


- Radiación solar en total anual más alta del mundo debido a las condiciones geográficas y atmosféricas: altura, nubosidad, aerosoles.

Solar radiation in Chile

- Highest level of DNI in the world: Atacama desert shows values between reaching 3500 kWh/m² per year ***and more!***
- Low cloud cover presence and low aerosols content.
- More clouds in the coast.
- Low decrease with higher latitudes

- ***Crucero (and others):*** represents the radiation conditions of northern and central Chile in a place of relevance in terms of energy demand for the mining industry
  - **DNI:** yearly total of 3389 kWh/m²
  - Seasonal variation
  - More than 300 days per year with clear sky



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Estado Actual

- Solar es la principal de las renovables en Chile.
- Única con PES lo que asegura una mayor proyección (I+D e industria).

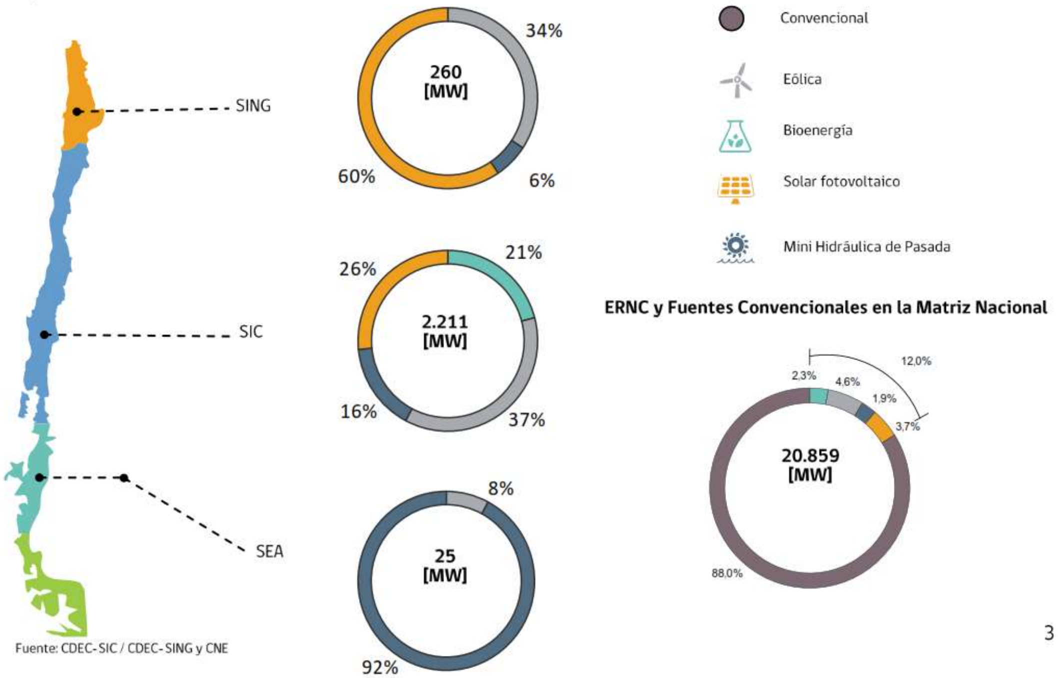
Cuadro Resumen—Estado de Proyectos ERNC

Tecnología	Operación [MW] (*)	Construcción [MW]	RCA Aprobada [MW]	En Calificación [MW]
Biomasa	417	0	112	47
Biogás	48	0	8	0
Eólica	910	428	5.966	1.905
Geotermia	0	48	120	0
Mini Hidro	433	25	455	75
Solar - PV	1.056	2.082	11.266	4.826
Solar - CSP	0	110	980	475
Total	2.866	2.692	18.907	7.328

2 Capacidad Instalada de Generación Eléctrica

La potencia instalada en base a tecnologías ERNC, al **29 de febrero de 2016**, asciende a un total de **2.496 MW (*)**. De dicho valor, un **88,59%** (2.211 MW) se ubica en el SIC, en tanto que un **10,40%** (260 MW) se encuentra conectado al SING. El restante **1,02%** (25 MW) se encuentra en el Sistema Eléctrico de Aysén.
La capacidad ERNC instalada corresponde a un **11,97%** de la capacidad eléctrica total en los sistemas eléctricos nacionales.
(*) Adicionalmente, el SIC cuenta con 16 centrales ERNC en prueba, que suman 161 MW. En el caso del SING, cuenta con 4 centrales en pruebas, los que corresponden a 209 MW.

Capacidad Instalada ERNC



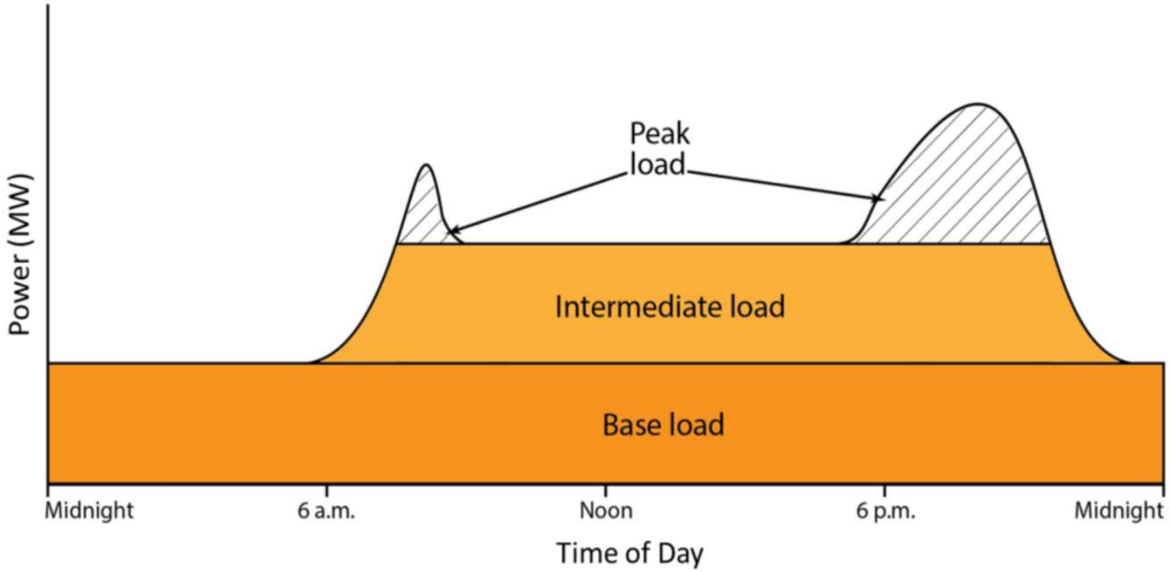
Fuente: CDEC-SIC / CDEC-SING y CNE

3

¿Pueden CSP y PV Satisfacer Demanda por separado?

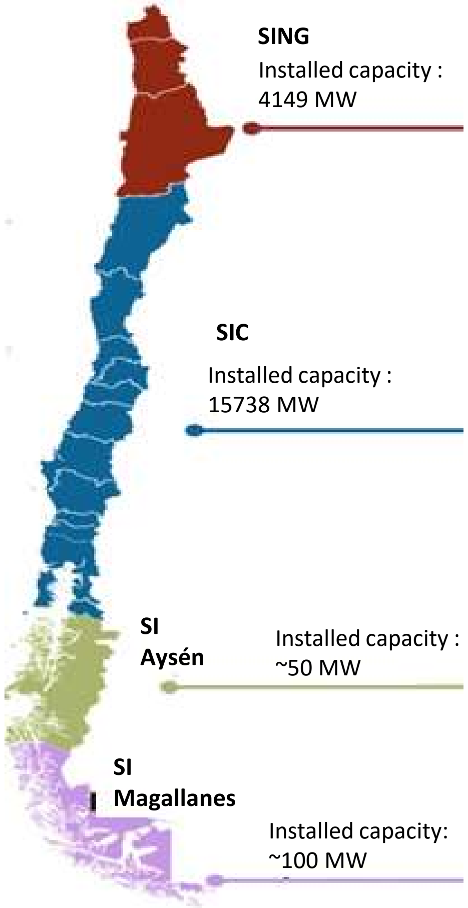
Perfil de Demanda

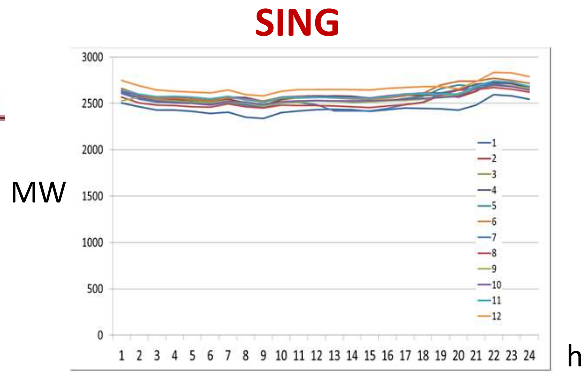
- La demanda puede ser base, intermedia o punta.
- La curva de demanda depende de las características del sistema productivo (actividad económica).

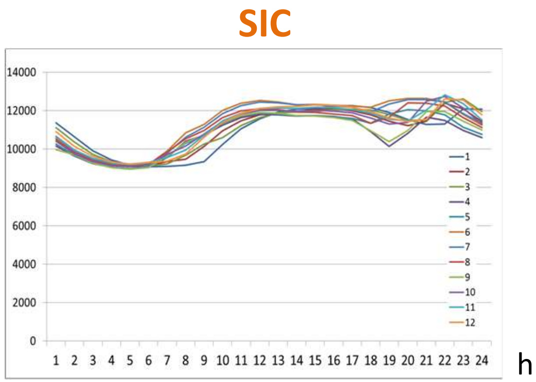


- Tradicionalmente la demanda base se cubre con plantas a carbón, hidroeléctricas, o nucleares.
- Demanda punta es cubierta con medios de generación de respuesta rápida (turbinas a gas).
- La contradicción de solar PV: despacha con prioridad (por costo marginal) pero es variable, obligando a mantener reserva en giro.

Curvas de demanda en Chile





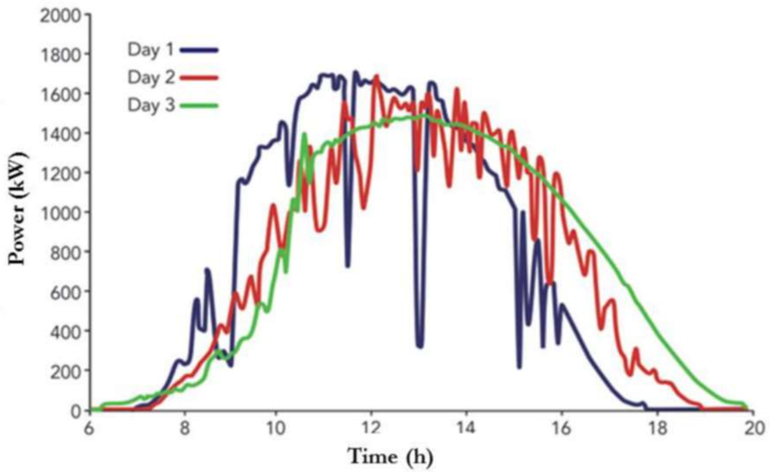


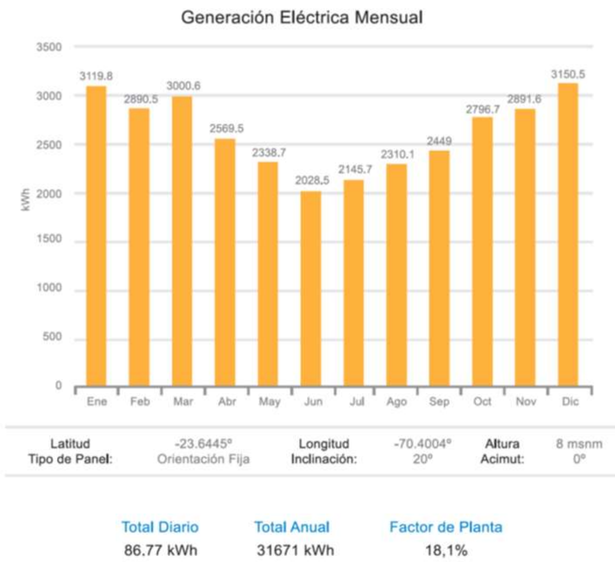
- Flat demand in SING makes PPAs for PV system difficult to compete with higher capacity factor technologies
- CSP with TES: higher LCOE

- **Opportunity:** Hybrid CSP + PV
  - TES: higher capacity factor + PV lower costs
  - Examples:
    - Abengoa| Atacama 1 | 110 + 100 MW
    - Solar Reserve | Copiapó | 2x130 + 150 MW

Variabilidad en Producción PV

- Tres escalas temporales principales:
  - Intrahoraria: variabilidad por nubes
  - Ciclo diario: variabilidad de acuerdo a parámetros geométricos tierra-sol (horas de sol, forma de la curva, total diario).
  - Ciclo anual: producción verano/invierno.





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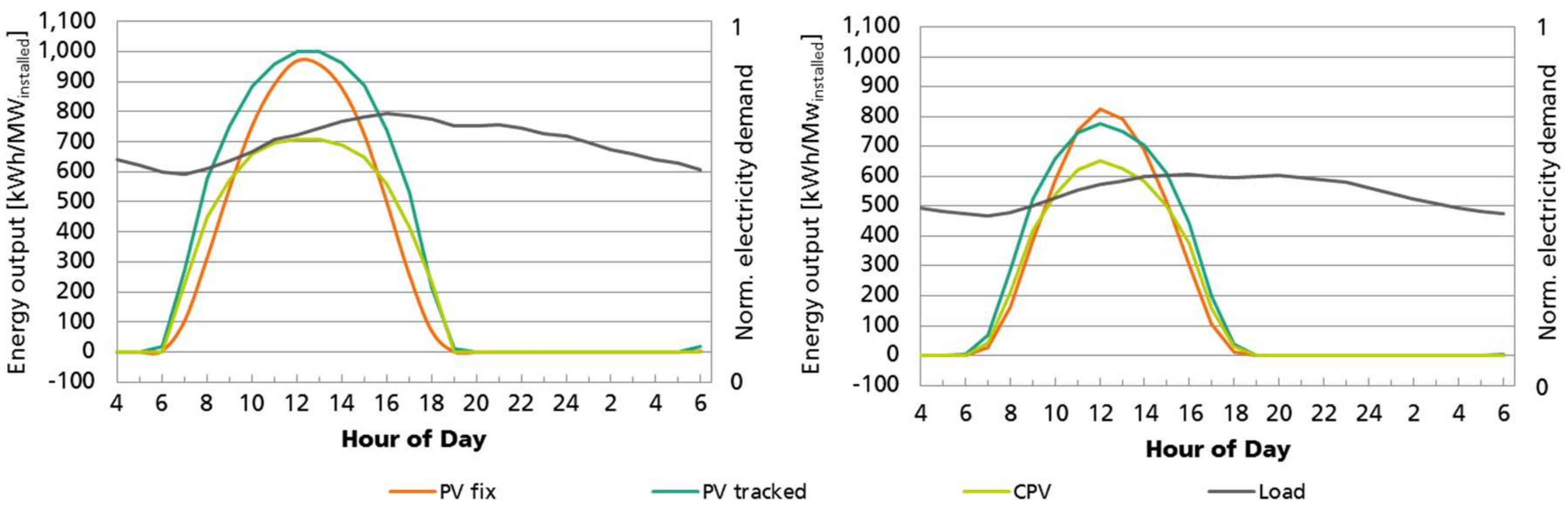
Perfiles de Generación Horaria PV

– PV produce directamente siguiendo la irradiancia: ciclo día/noche
– Seguimiento aumenta la producción (1 o 2 ejes) y CPV produce menos (solo DNI)
– Aproximaciones por sobre o bajo la demanda: en cualquier caso PV solo cubre aprox. 30% de la demanda diaria → sobredimensionar y usar almacenamiento

Día Ejemplo

Promedio Anual



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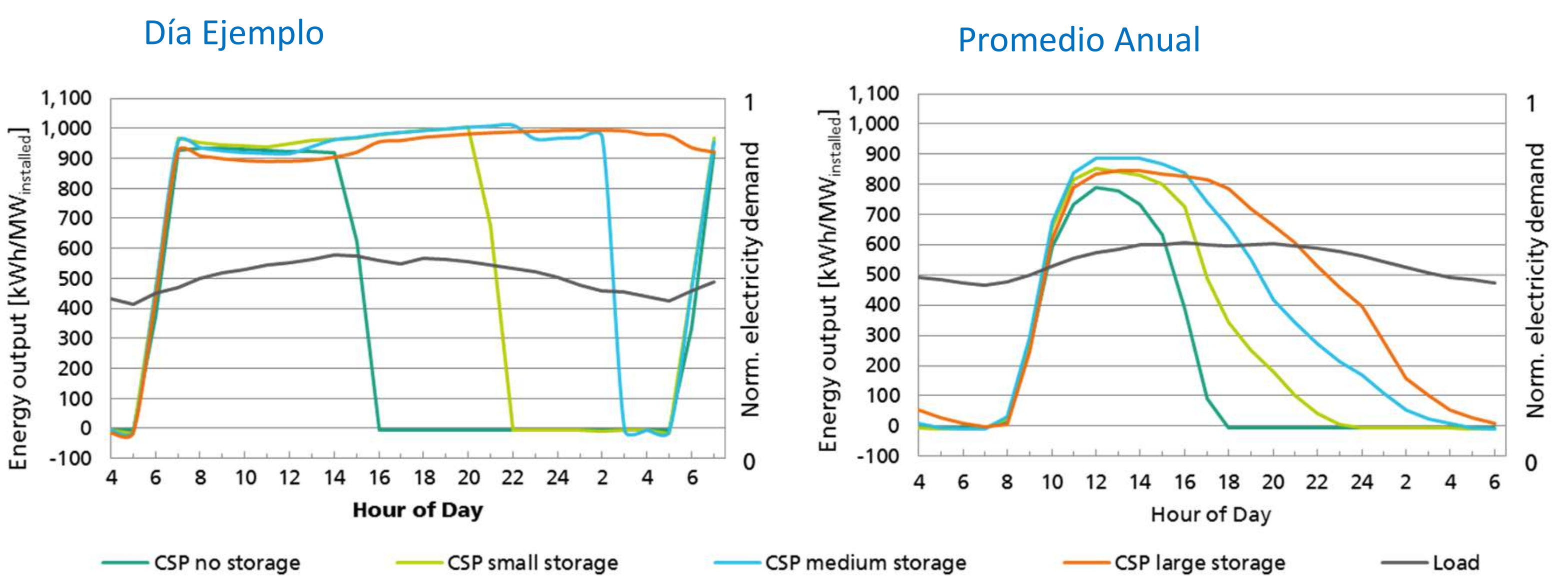
Perfiles de Generación Horaria CSP

– CSP con almacenamiento térmico (TES) require sobredimensionamiento (SM >1) para almacenar y despachar después de la puesta de sol.

– Con SM grandes, incluso se puede obtener generación 24/7

– Con la tecnología actual CSP sigue siendo caro



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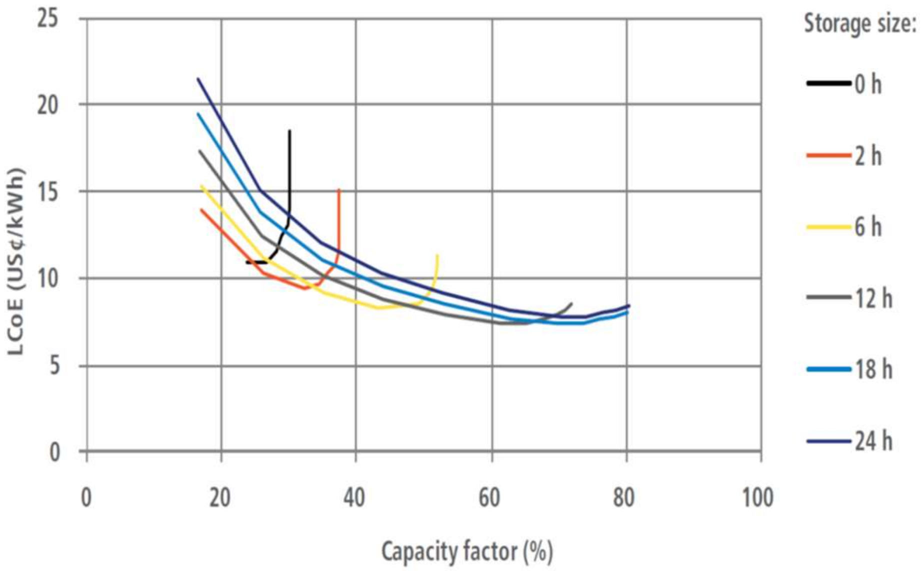
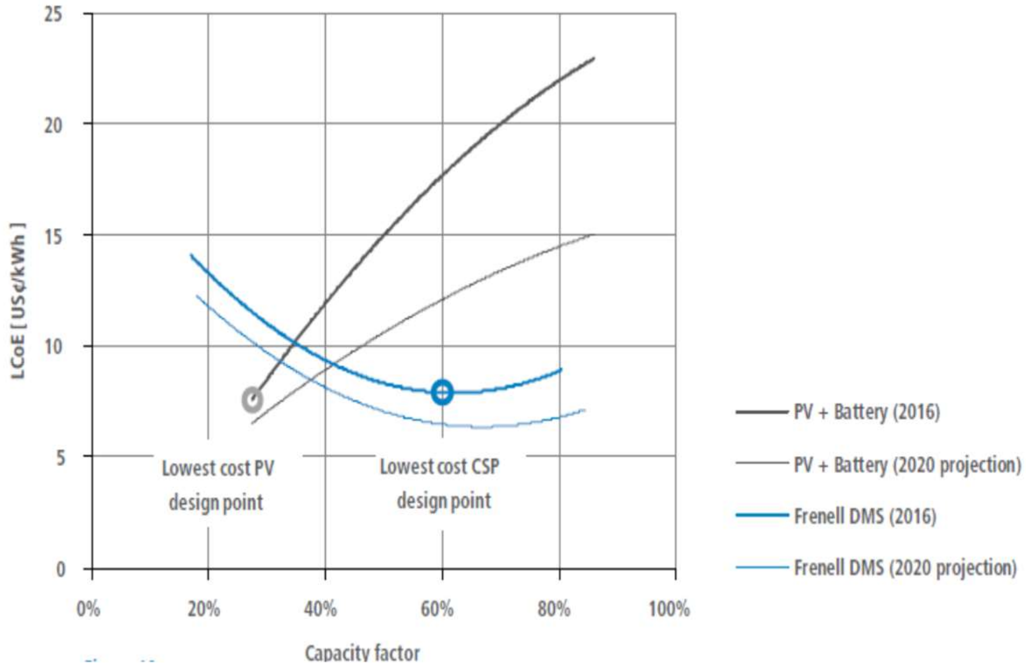
LCOE vs Factor de Planta y Capacidad TES, BESS





Frenell, White Paper 2016

Resumen

- PV produce en ciclos diarios con alta variabilidad por nubes
- CSP genera con perfiles más suaves por inercia térmica y puede tomar ventaja de usar TES
- Tamaño de TES óptimo para CSP permite obtener mínimo costo
- Costo de PV + BES aumenta con la capacidad

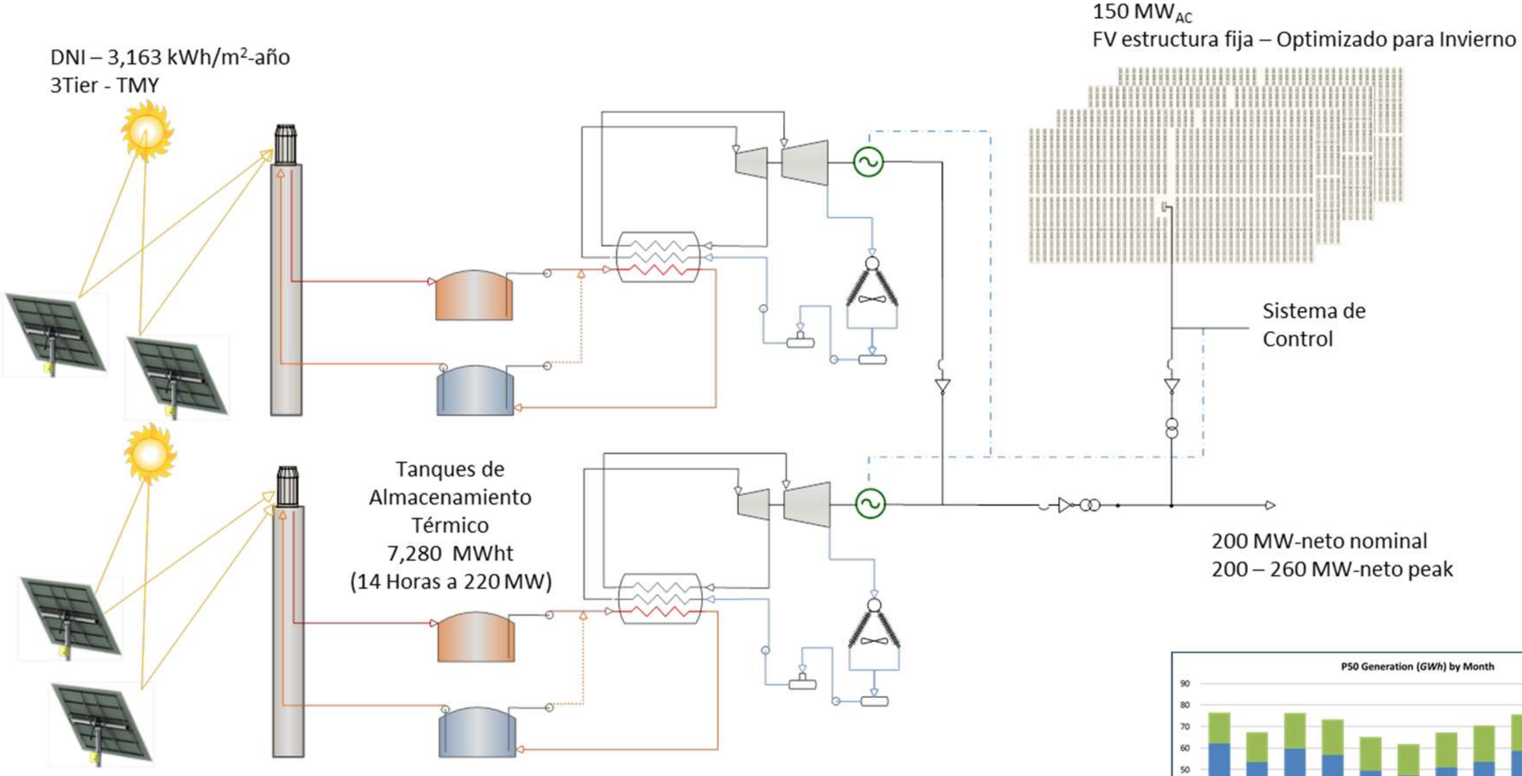
- Si cada tecnología por separado tiene desventajas…¿por qué no combinarlas y aprovechar sus ventajas?

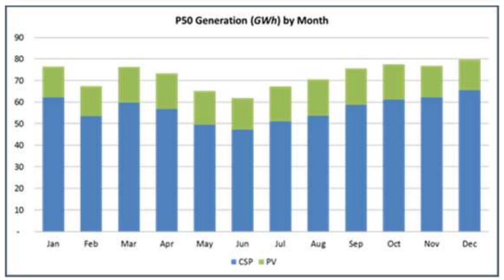
Hibridización CSP + PV

- Combina una planta CSP+TES con una planta PV (fija o seguimiento).
- Aprovecha las ventajas de cada tecnología: bajo costo PV, y despachabilidad CSP+TES.

- Aumenta el factor de planta sobre los valores de PV y CSP.
- Permite mayor producción sin necesidad de aumentar campo solar y TES.
- Reduce la variabilidad de PV.
- Facilita la generación base.
- Baja el costo nivelado de la CSP.

Proyecto Copiapó Solar





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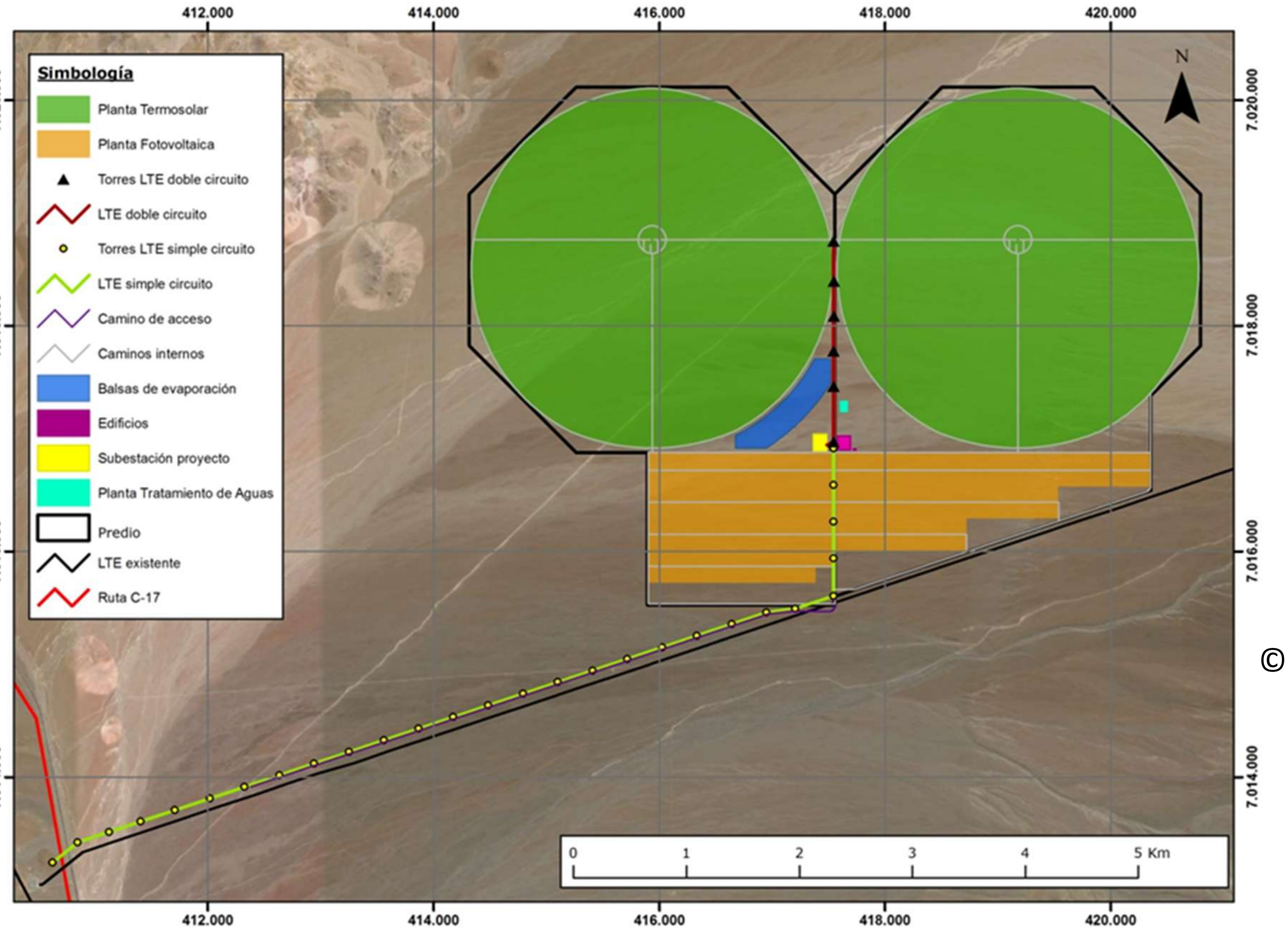

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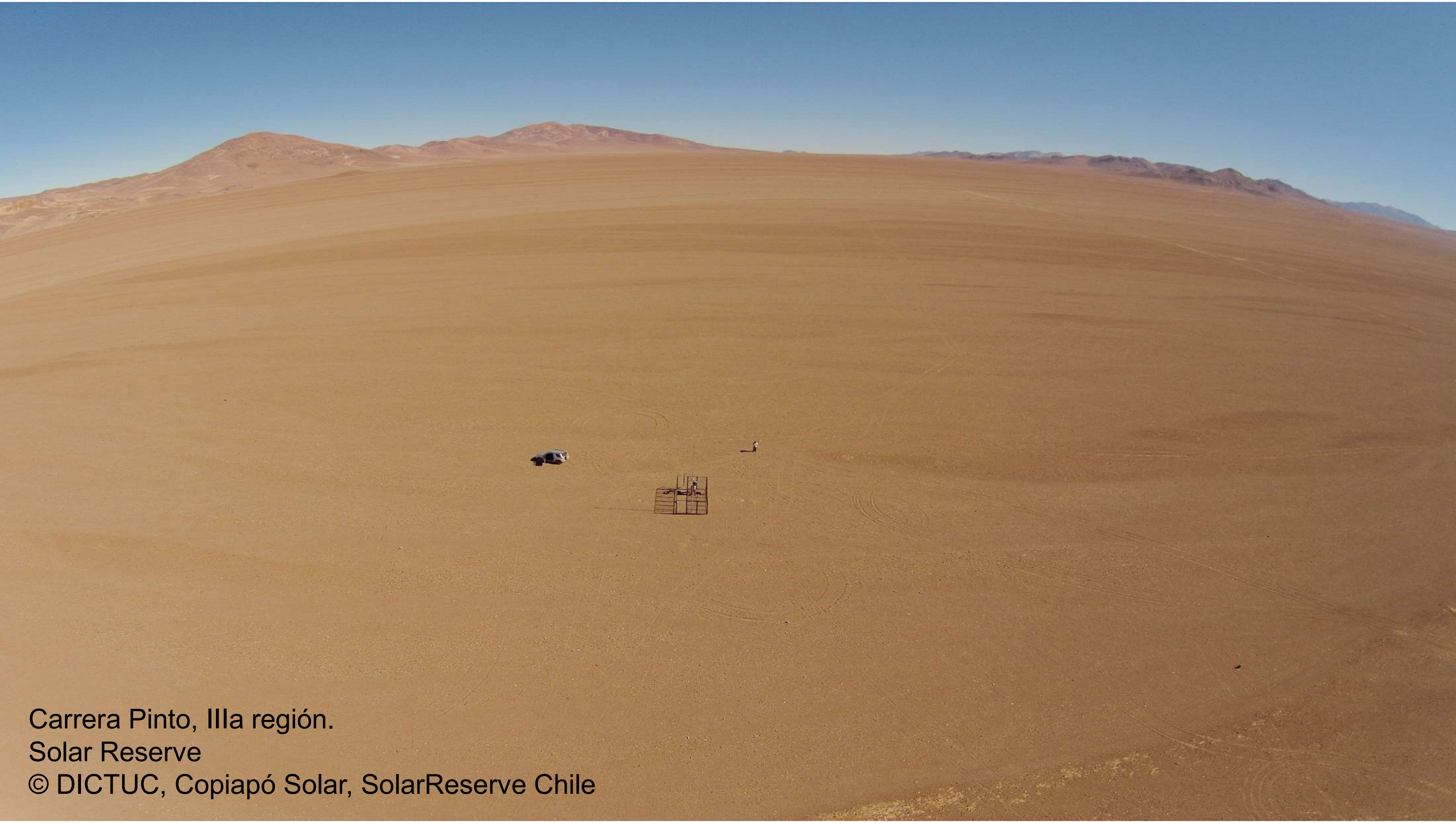


Carrera Pinto, IIIa región.
Solar Reserve

Análisis Tecno-Económico de plantas Híbridas

CSP+TES

+

PV+BES

Adriana Zurita PhD Student
(Carlos Mata, Carlos Felbol, Carlos Valenzuela)

PV and CSP technologies

Solar PV:

- PV technology represents 7% of the national installed capacity.
- Dramatic decline of PV technology costs in the last years.
- Main limitations are the variability and intermittence of the electricity production.

CSP + TES:

- Suitable option to improve dispatchability and capacity factors.
- TES integration: baseload generation profile.
- 110MW of solar CSP in construction in Chile.

Hybrid CSP+PV +TES

- Particular interest of the industry in hybridization.
- Projects worldwide: in South Africa, Chile and Israel
- Constant power output
- Takes advantage of PV low costs.

Hybrid CSP+PV+ TES+ BESS

- Evaluate the interaction between two types of energy storage technologies.
- Batteries have good projections for implementation to the future. (cost reductions)

Hybrid CSP+PV concept plant

Location and Solar Resource

- Crucero (Lat. -22.24° S and Lon. -69.51° W)
- Yearly total for DNI: 3389 kWh/m^2

CSP technology

- Central Receiver system
- 115MWgross of power block (Net output of100MWe)
- Minimum operation point of the power block: 25%
- Solar multiple from 1,5 to 3,5

TES system

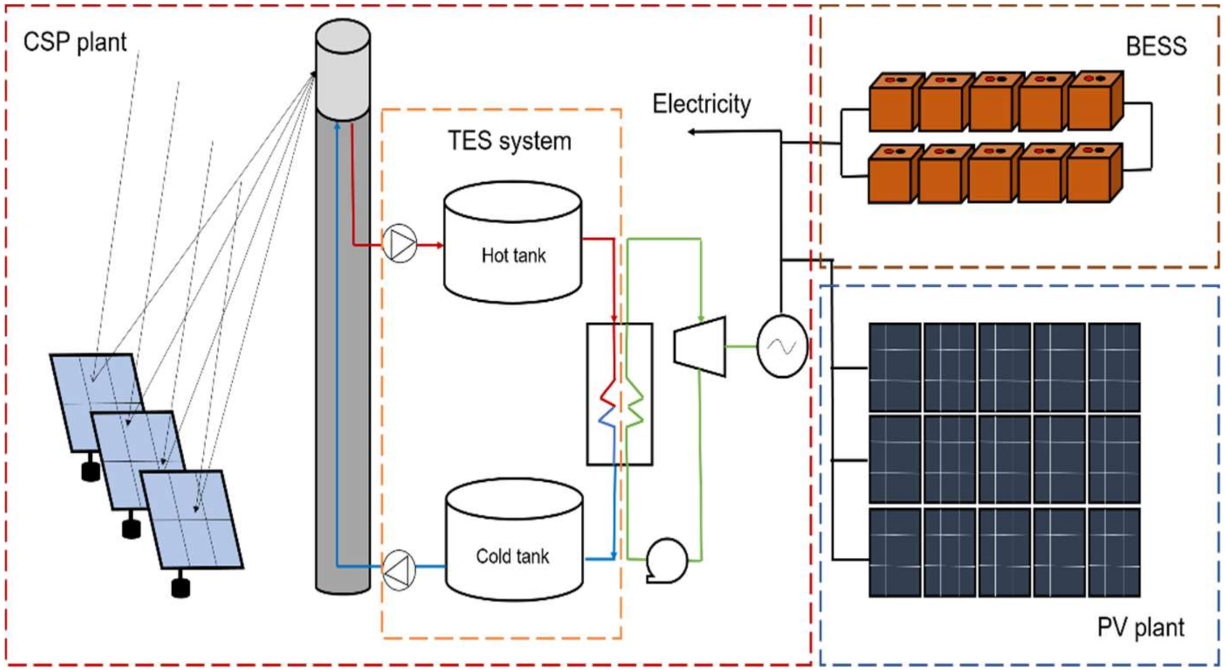
- Two-tank direct TES system
- HTF (Heat Transfer Fluid): Molten salts (60%$NaNO_3$-40%KNO_3)
- TES hours from 6h-18h

PV technology

- Fixed-angle PV plant with a 30° slope to maximize winter production
- PV size from 50MW-150MW

BESS (Battery Energy System Storage)

- Lead-acid battery bank
- BESS size from 0MWh-1000MWh



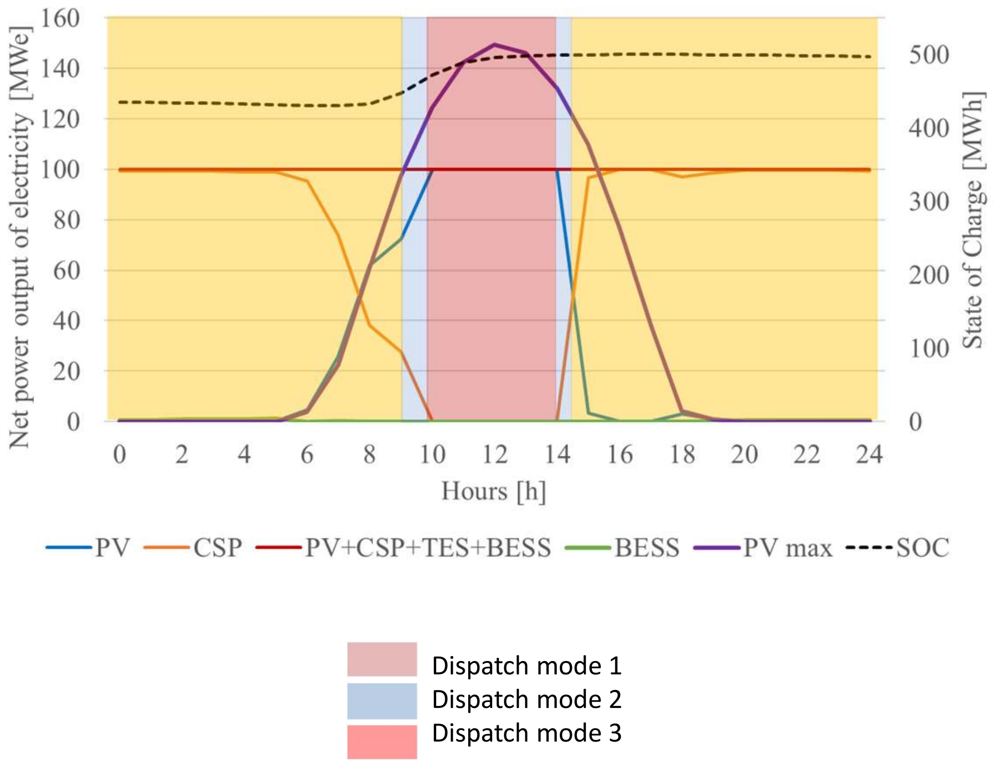
Schematic diagram of the hybrid CSP+PV plant integrated with TES and BESS

Operation modes

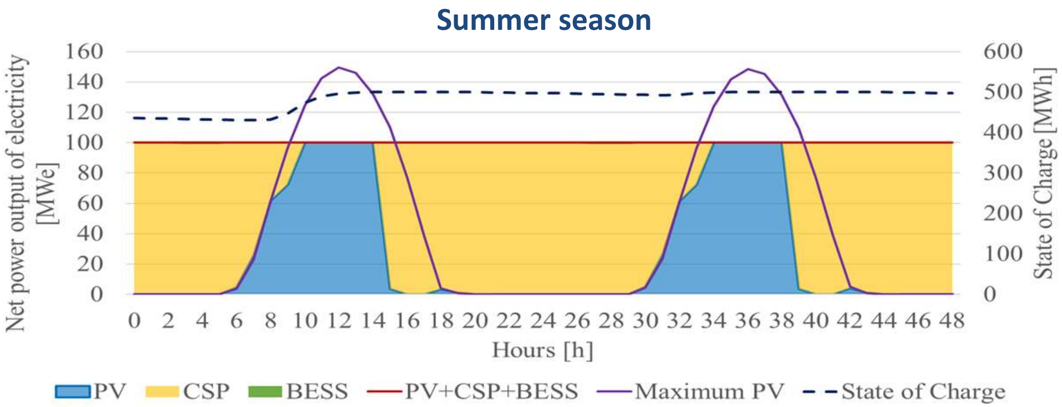
- Simulations were performed in the software **TRNSYS**.
- Annual performance of the thermal and electric systems under transient conditions.
- Meteorological and irradiation data were used.
- The dispatch strategy of the hybrid plant is to deliver100MWe to the grid.

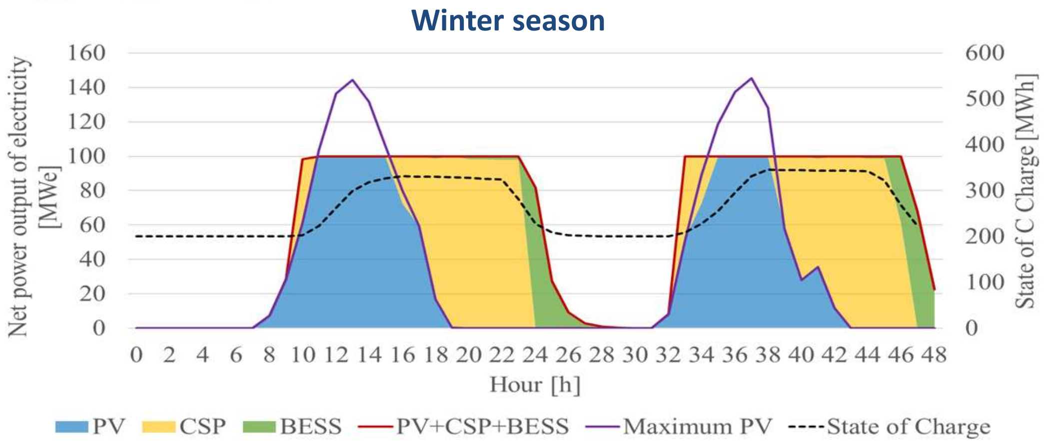
3 operation modes:

1. PV production < 75MW → CSP plant operates to cover the energy deficit.
2. PV production >75MW → CSP plant operates at minimum condition (25%) and PV energy surplus is stored in the BESS.
3. PV production ≥100MW → CSP plant is turned-off and PV energy surplus is stored in the BESS.



Summer and Winter operation





Configuration:

- PV size: 150MW
- BESS size: 500 MWh
- TES hours: 12h
- Solar Multiple: 1.7

Summer:

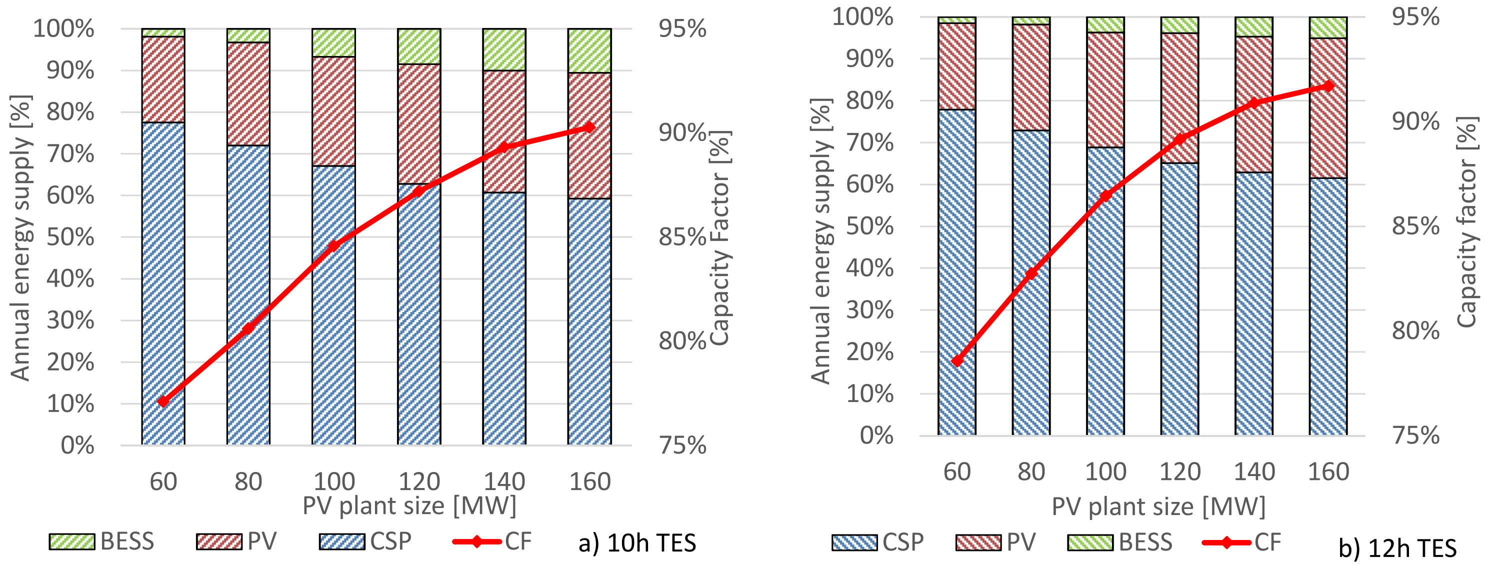
- Baseload capacity is achieved only using PV and CSP.
- Battery bank **is fully charged** when PV net output exceeds 100MW, but during the night , the energy stored in TES is enough to cover the demand, so the BESS remains without being discharged.

Winter:

- The BESS is partially charged when there's a surplus of PV energy. During the night, the TES and BESS are fully discharged and the hybrid plant runs out of energy.

Scaling Analysis

- It was obtained that a PV plant capacity above 100MW is required to obtain a more relevant participation of the BESS, because below this value is negligible (less than 5%)
- As larger the PV plant size it was obtained higher capacity factors and a decrease of the CSP contribution.



Energy distribution and capacity factor for different PV plant sizes fixing TES hours in: a) 10 h b)12h with a BESS size of 500MWh

- Also, a larger TES size implies a smaller contribution of the battery bank to the total generation.

Cost data

TABLE 1. Economic parameters of the CSP plant [14]

Description	Unit	Value
Direct capital cost		
Site improvements	USD/m^2	16
Heliostat field	USD/m^2	145
Balance of plant	USD/kWe	340
Power block	USD/kWe	1100
Storage	USD/kWht	24
Fixed tower cost	USD	3,000,000
Tower cost scaling exponent		0.0113
Receiver reference cost	USD	103,000,000
Receiver reference area	m^2	1,571
Receiver cost scaling exponent		0.7
Contingency		7%
Indirect capital cost		
EPC and owner costs	% of direct cost	13%
Total land costs	USD/acres	11000
Sale tax	%	0
Operation and Maintenance Costs		
Fixed cost by capacity	USD/kW-yr	66
Variable cost by generation	USD/MWh	3.5

TABLE 2. Economic parameters of the PV plant and BESS [15], [16]

Description	Unit	Value
PV plant		
Investment cost	USD/W	1.0
Operation and Maintenance Cost	USD/kW-yr	15
BESS		
Investment cost	USD/kWh	300

$$LCOE = \frac{A_f \cdot Inv_{costs} + C_{O\&M}}{E_{net} \cdot F_a}$$

$$A_f = \frac{r}{1 - \frac{1}{(1+r)^t}}$$

$$Inv_{costs} = Inv_{PV} + Inv_{CSP+TES} + Inv_{BESS}$$

$$C_{O\&M} = CO\&M_{PV} + CO\&M_{CSP+TES}$$

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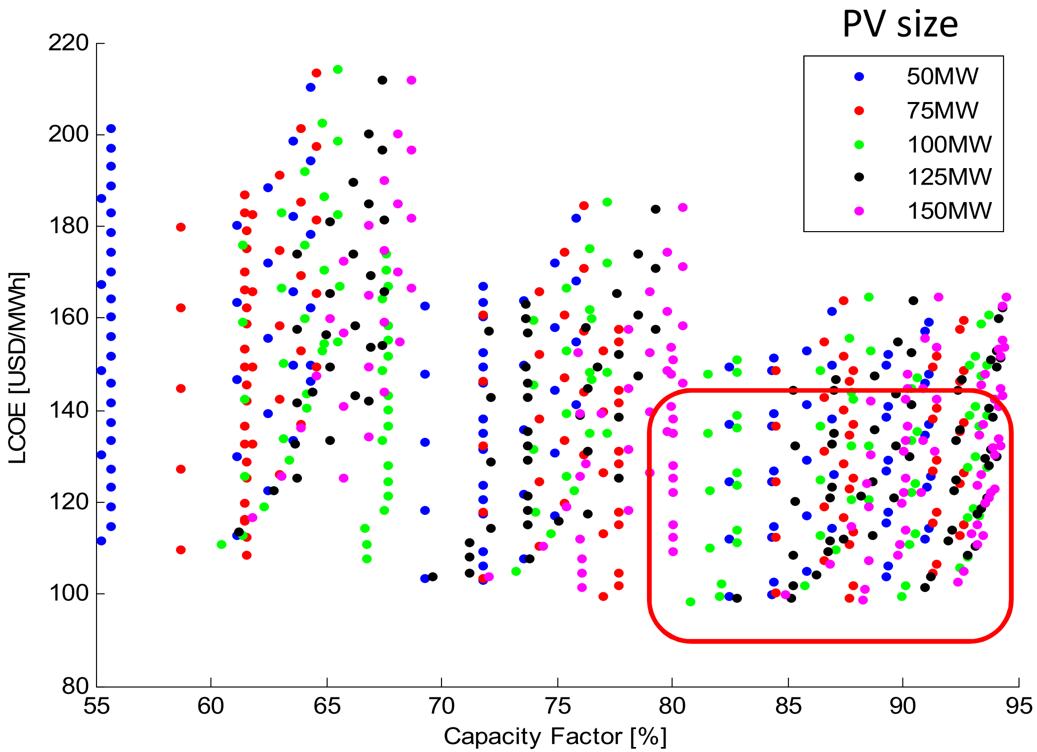
Cost and Capacity Factor



Parametric Analysis:

- PV size: 50MW-150MW
- SM: 1.5- 3.5
- TES hours: 6h-18h
- BESS size: 0MWh-1000MWh

- Results of parametric analysis show a zone with a group of points related to high capacity factors and LCOE values between 100 and 150 USD/MWh for different configurations of PV, SM, TES and BESS.

Optimal point?

- In general, LCOE increases with the BESS size but decreases with the TES size, while capacity factors are higher as the storage capacity is bigger.

Minimum LCOE was obtained for a configuration given by:

Minimum LCOE (USD/MWh)	Capacity Factor
98.46	85%

PV size (MW)	TES hours	Solar Multiple	BESS size (MWh)
100	12	2	0

- This result is produced by the still very high investment costs of BESS.
- However, batteries are expected to decrease their costs in order to support the generation of RE sources.
- Higher capacity factors can be achieved when a battery bank is included.

Summary and Conclusions

- Baseload generation of the hybrid plant can be achieved with capacity factors above 80%.
- **Investment costs of batteries are still very high for applications of large electricity storage**, however, technical analysis also showed the potential that BESS system can provide in terms of higher capacity factors and less dumped PV energy.
- Benefits of hybridization with BESS are traduced in **availability to store and exploit the surplus energy of the PV plant**, however, as the TES size increases, the percentage of the PV energy surplus that can be stored in the BESS decreases.
- For **larger PV capacities**, the energy surplus that is **dumped becomes more relevant** and an optimal sizing has to be accomplished in order to decrease the wasted energy.
- As future work, other type of battery technologies can be studied in order to cover the reduction cost of the market with including more parameters in the economic analysis of the battery system.

CSP+PV+Water

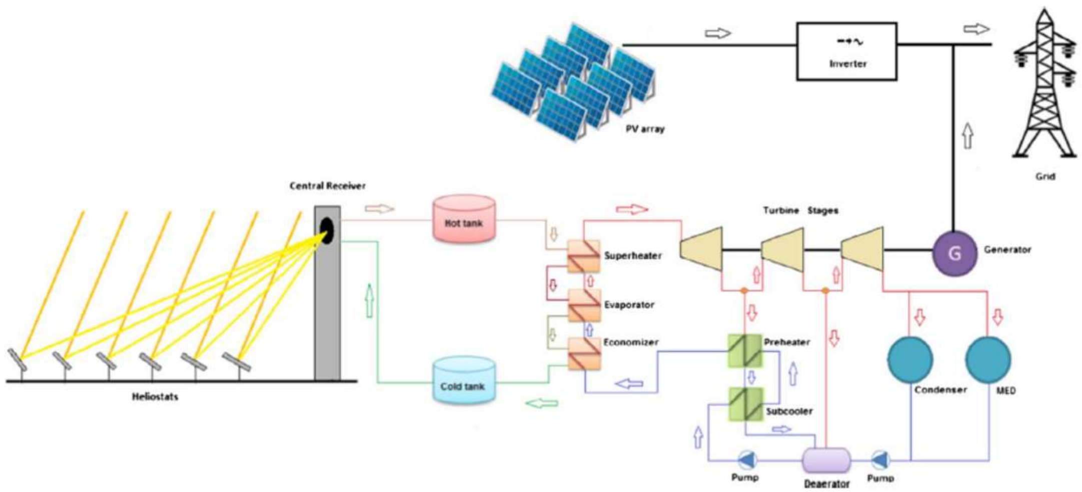


Fig. 1. Scheme of the CSP + PV + MED plant proposed.

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CSP + PV hybrid solar plants for power and water cogeneration in northern Chile

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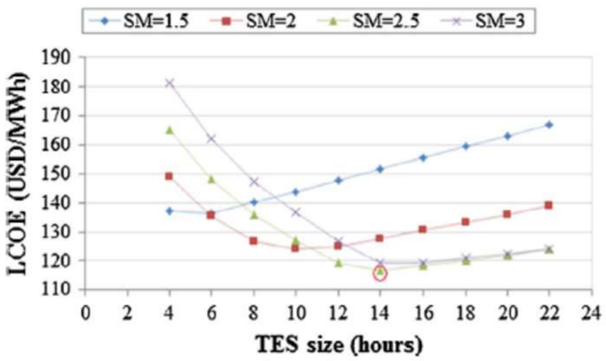
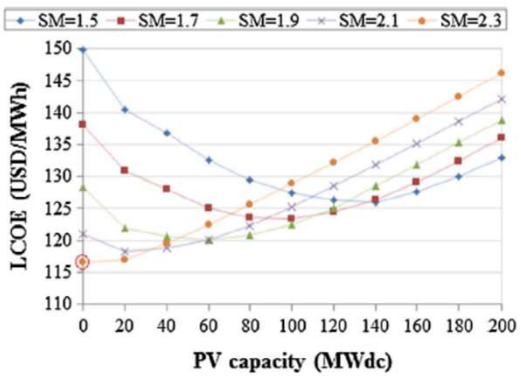
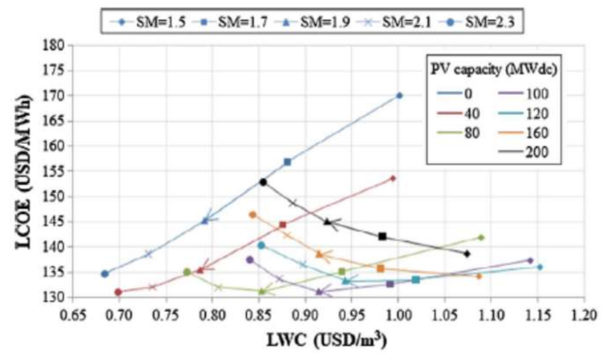
ABSTRACT

The integration between solar energy and seawater desalination is an interesting option in northern Chile due to a high solar potential in the Atacama Desert, where most of the mining operations are located. This industry is intensive in electricity and water consumption; therefore, there is an ideal market opportunity. The CSP + PV plant has the benefits of reduce costs, increase capacity factor and offer high dispatchability, while the integration of a MED plant presents the advantage of using the waste heat. A CSP + PV + MED plant model was performed in TRNSYS implementing a dispatch strategy that prioritize PV output and minimize the turbine shutdowns. The results show that a CSP + PV + MED plant presents a capacity factor 7.6% lower than CSP + PV plant. Regarding the operation of the turbine and the MED plant, the configurations that maximize the operating hours also maximize the performance at partial load, obtaining different PV capacities for the maximum operation hours of the turbine and MED plant. For the CSP + PV + MED plant, different CSP and PV plant configuration between optimal or suboptimal were found to minimize the LCOE and LWC. Also, the best combination between LCOE and LWC is achieved with a CSP close to optimal configuration and suboptimal PV.







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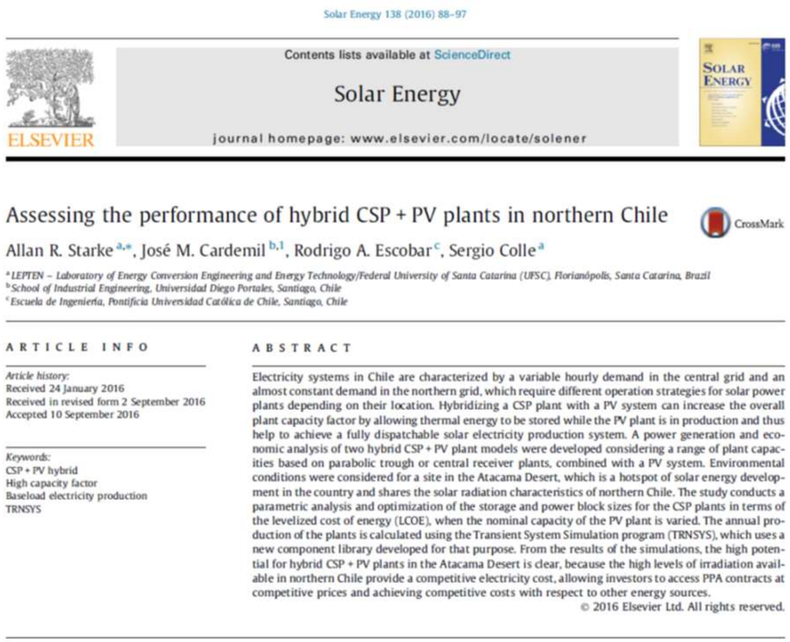
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Assessing the performance of hybrid CSP + PV plants in northern Chile

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TRNSYS

ABSTRACT

Electricity systems in Chile are characterized by a variable hourly demand in the central grid and an almost constant demand in the northern grid, which require different operation strategies for solar power plants depending on their location. Hybridizing a CSP plant with a PV system can increase the overall plant capacity factor by allowing thermal energy to be stored while the PV plant is in production and thus help to achieve a fully dispatchable solar electricity production system. A power generation and economic analysis of two hybrid CSP + PV plant models were developed considering a range of plant capacities based on parabolic trough or central receiver plants, combined with a PV system. Environmental conditions were considered for a site in the Atacama Desert, which is a hotspot of solar energy development in the country and shares the solar radiation characteristics of northern Chile. The study conducts a parametric analysis and optimization of the storage and power block sizes for the CSP plants in terms of the levelized cost of energy (LCOE), when the nominal capacity of the PV plant is varied. The annual production of the plants is calculated using the Transient System Simulation program (TRNSYS), which uses a new component library developed for that purpose. From the results of the simulations, the high potential for hybrid CSP + PV plants in the Atacama Desert is clear, because the high levels of irradiation available in northern Chile provide a competitive electricity cost, allowing investors to access PPA contracts at competitive prices and achieving competitive costs with respect to other energy sources.

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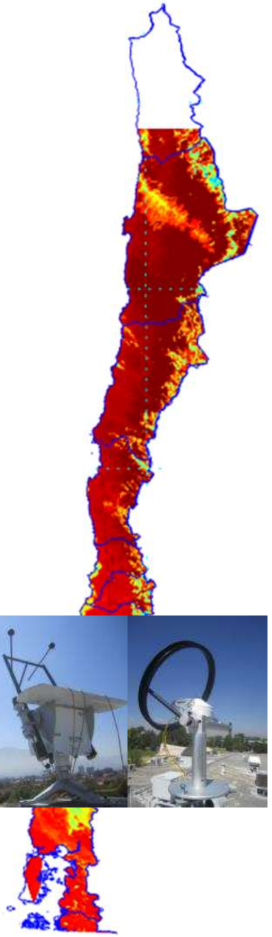
Plantas Híbridas CSP+TES+PV+BES



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