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Technology Mix
for the “Diego de Almagro Solar Technology District” in Chile

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DLR Deutsches Zentrum für Luft- und Raumfahrt
German Aerospace Center

M+W GROUP

CORFO

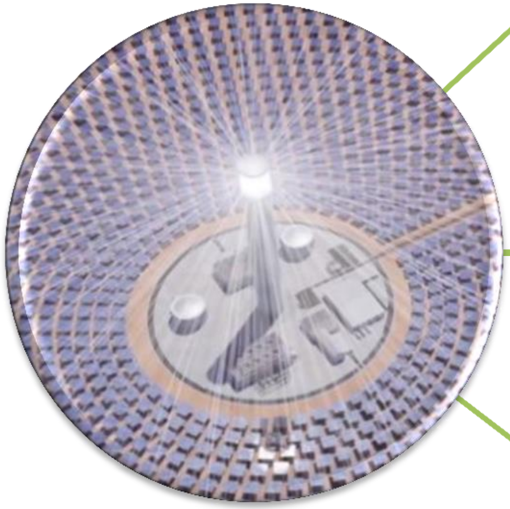
FCh FUNDACIÓN CHILE

ISC International Solar Energy Research Center Konstanz

What is the „Diego de Almagro Solar Technology District“?

- It is a large-scale solar park initiated by the “Comité Solar” of the Chilean Goverment through CORFO
- The project is located at the southern region of the Atacama Desert, near the Diego de Almagro town.
- It includes the development, implementation and operation & maintenance of serveral power plants
- The installed capacity is estimated between 750 MWe and 1.0 GWe
- Being a solar park, it offers shared infrastructure such as:
    - Internal transmission lines
    - Transformer substation
    - High voltage transmission line to the Substation “Cumbres”
    - Connection to the main transmission system
    - O&M of the electrical infrastructure
- Current project status: on hold

What is relevant about this study?



Energy Demand

- Baseload Power Generation 24/7
- Chilean Energy Market
- Spot market prices depending on hydrology scenario

Local Conditions

- Abundant solar irradiation
- Almost no fresh water available

Technology Options

- CSP and/or PV
- No fossil-fuel hybridization
- Electricity import allowed

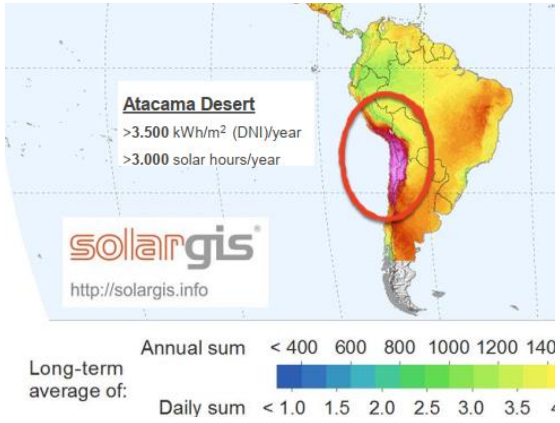


Image sources: http://desafio2030.cl/2017/12/diego-de-almagro-la-ciudad-del-sol/
R. Mancilla, SolarPACES 2017, Solar Energy Program, CORFO

Structure of the Study

1. Analysis of technology options
2. Techno-Economic modelling
3. Optimization strategy
4. Automatic batch simulations, search and selection of optimal configurations
5. Plant specification and Layout

Energy Generation Technologies Evaluated

CSP

Parabolic Trough
- ❑ Thermal Oil
- ❑ Molten Salt

Solar Tower
- ❑ Molten Salt

PV

Poly-Crystalline (Monofacial)
- ❑ 1-axis tracked

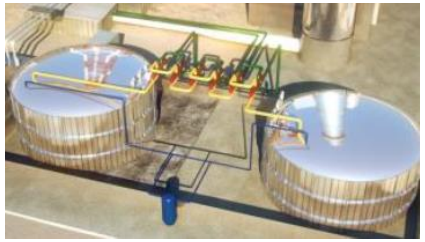
Bifacial PV
- ❑ 1-axis tracked

Technology Pre-Selection

PV Bifacial and Monofacial were compared, and due to lower LCOE (-11%), only Bifacial systems were selected for the technical simulation.

Energy Storage Technologies Evaluated

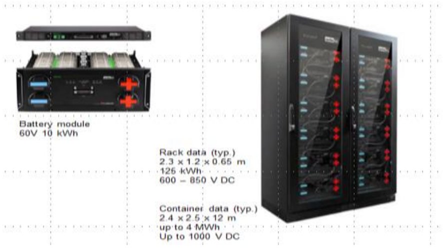
CSP TES



Thermal Storage

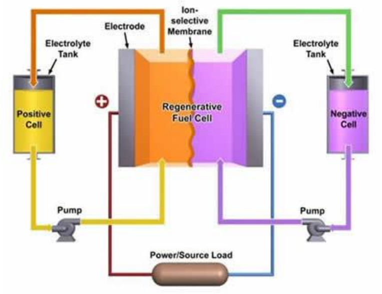
- ❑ Two-tank molten salt

PV Battery



Electro-chemical with internal storage

- ❑ Lithium-ion



Electro-chemical with external storage

- ❑ Redox Flow

Storage Pre-Selection

Methodology

Main Boundary Conditions for Optimization:

Two pillars:

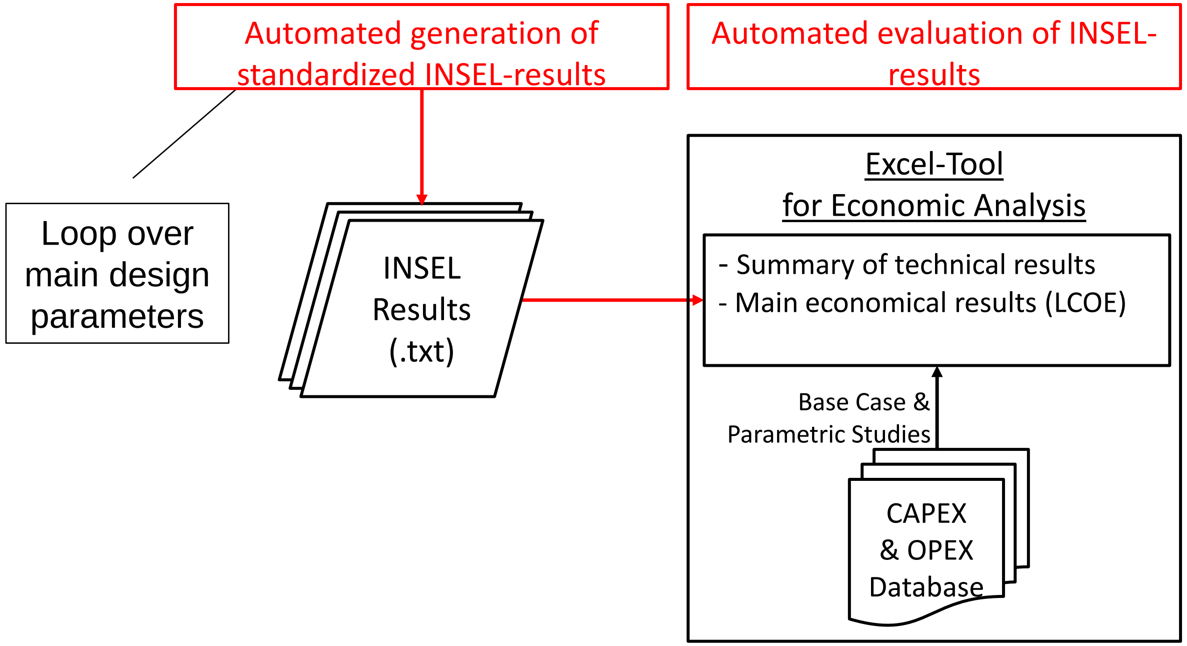
- Attraction for private investment
- Quality of supply (24/7 secure supply)

→ **Optimization towards minimum LCOE**

- Water costs included in the LCOE calculation
- Difference in cost between electrical power imports and exports with hourly spot market prices

Methodology

→ Optimization towards minimum LCOE



Parametric variation ranges:

	Minimum	Maximum	Incremental Step
Solar Multiple [-]	1.0	2.5	0.25
TES capacity [h]	2.5	15.0	2.5
PV capacity [MWp]	0.0	152.0	12.7 / 25.7
Battery capacity [h]	0.0	0.5	0.5

Four cases were evaluated regarding the **hydrology** and client’s **import station**:

	Hydrology Dry	Hydrology Wet
Import from Cumbres 500 S/E	Case 1	Case 3
Import from Pan de Azúcar 220 S/E	Case 2	Case 4

*Number of runs: 756 parametric combinations * 4 cases = 3024*

Export station fixed at Cumbres 500 S/E (located next to the Solar Park)

Levelized Cost of Electricity Calculation

$$LCOE_{with\ SM} = \frac{TLCC_{CSP} + TLCC_{PV} + ImE - ExR}{\sum_{n=1}^{N} \frac{API_n}{(1+d)^n}}$$

Typical LCOE equation:

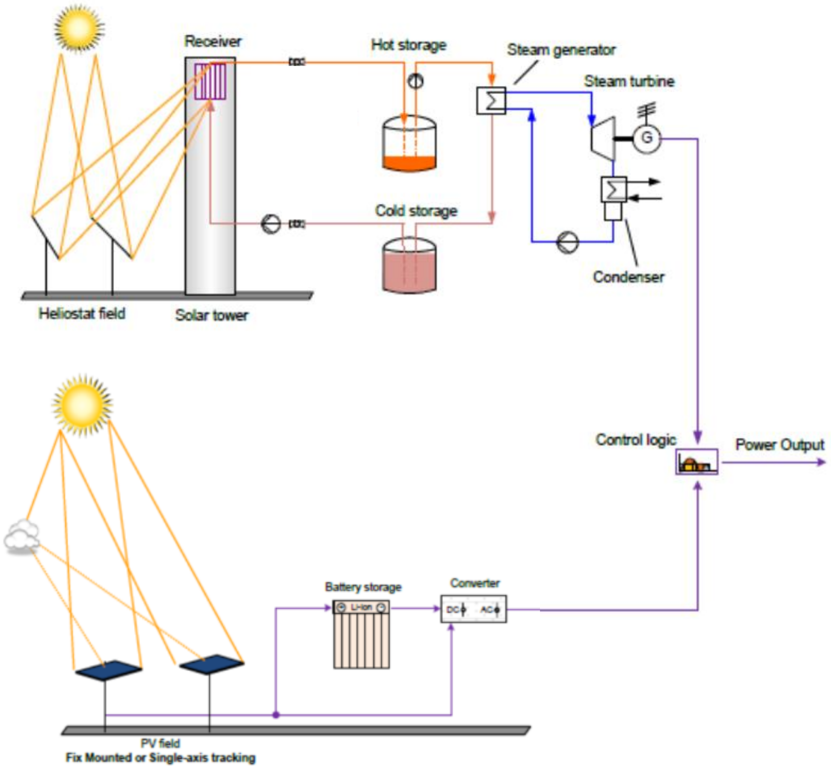
$$LCOE = \frac{TLCC_{CSP} + TLCC_{PV}}{\sum_{n=1}^{N} \frac{Q_{n,CSP} + Q_{n,PV}}{(1+d)^n}}$$

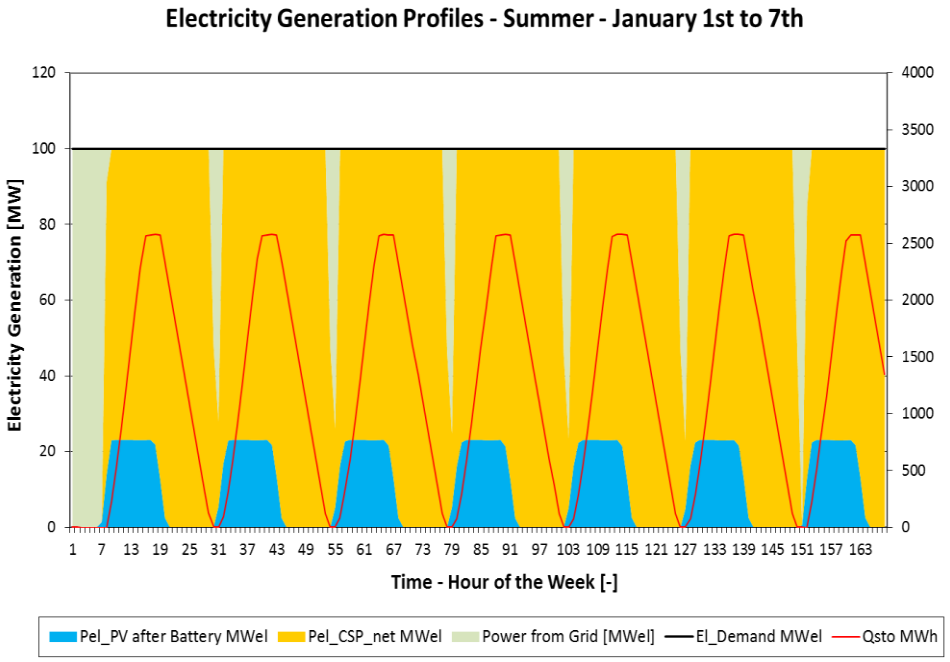
TLCC: total life-cycle cost
ImE: import expenditures
ExR: export revenues
API: annual power imports
n: year
d: Discount Rate

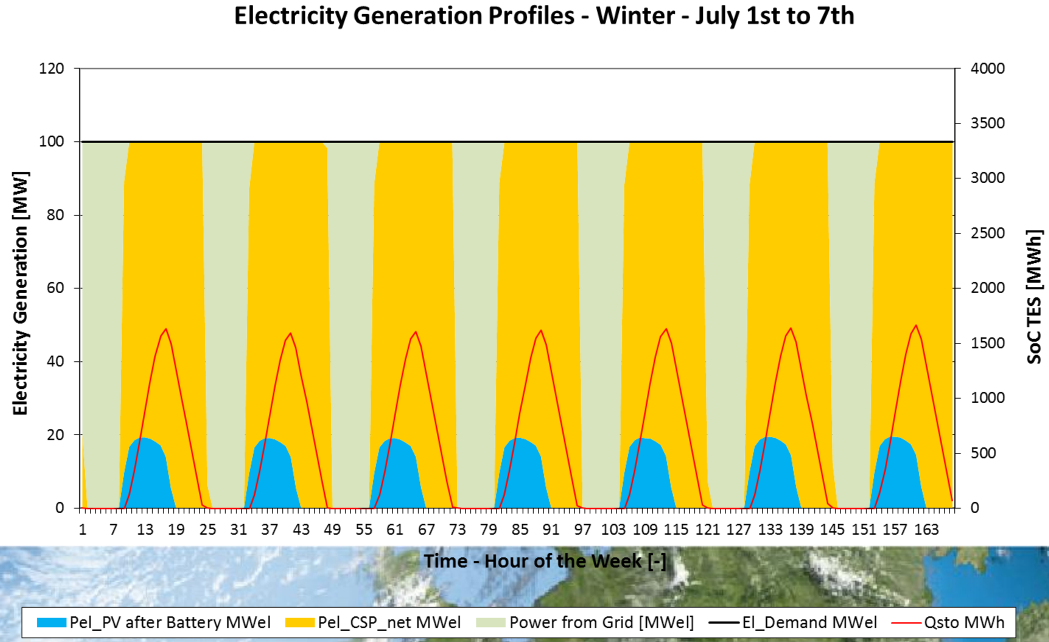
$$ExR = \sum_{n=1}^{N} \frac{\sum_{=1}^{8760} MC_{h,n} * NEG_{h,n}}{(1+d)^n};\ ImE = \sum_{n=1}^{N} \frac{MC_n * API}{(1+d)^n}$$

MC: marginal costs at the spot market
h: hour
NEG: net electricity generation

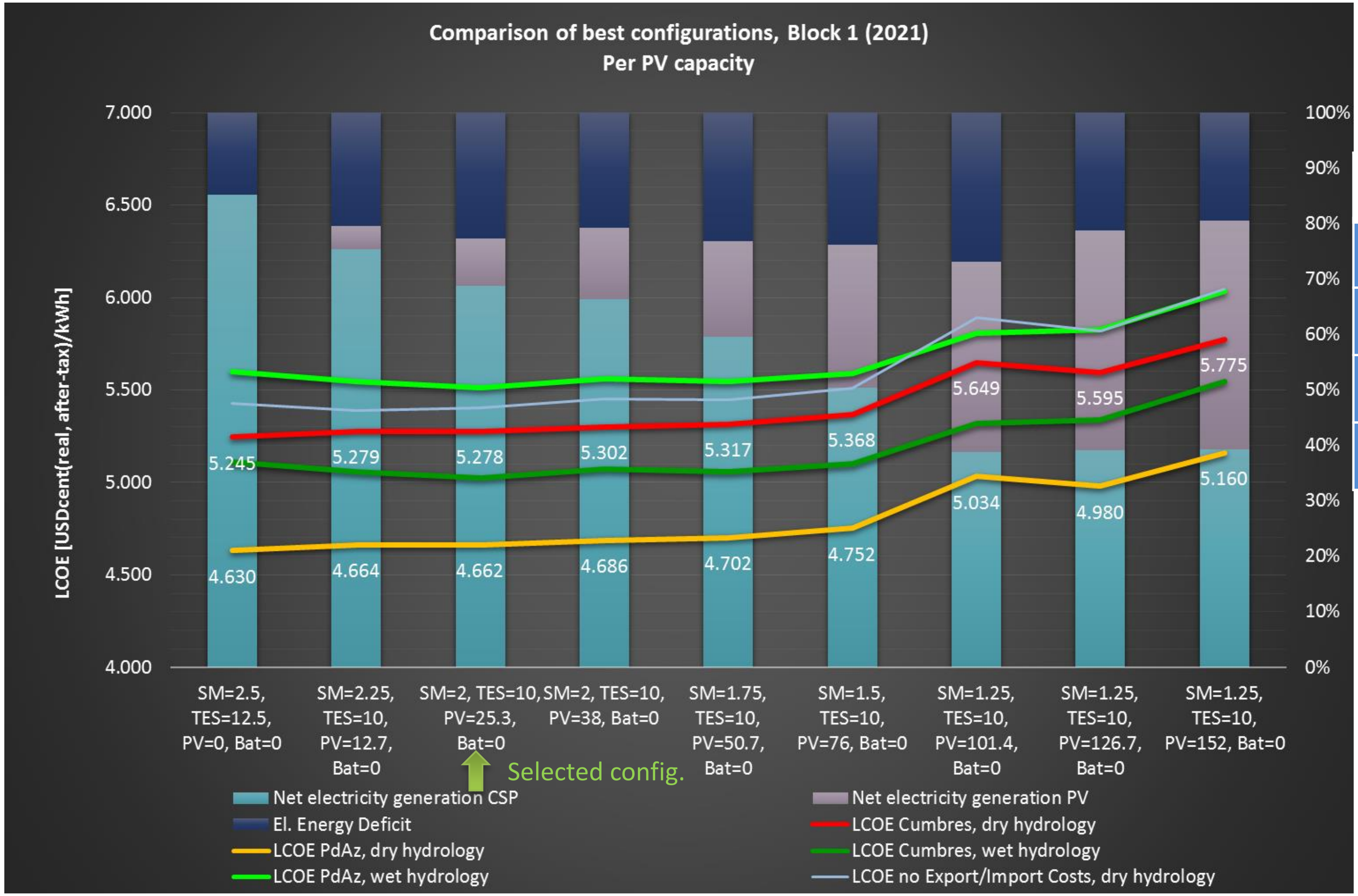
Operation Strategy







Results



LCOE results. All unit in [USDcent/kWh]

	Case 1	Case 2	Case 3	Case 4
Total LCOE	5.28	4.66	5.03	5.51
Partial LCOE CSP	5.66			
Partial LCOE PV	3.36			
Grid deficit	4.83	1.98	3.75	6.00

	Hydrology Dry	Hydrology Wet
Import from Cumbres 500 S/E	Case 1	Case 3
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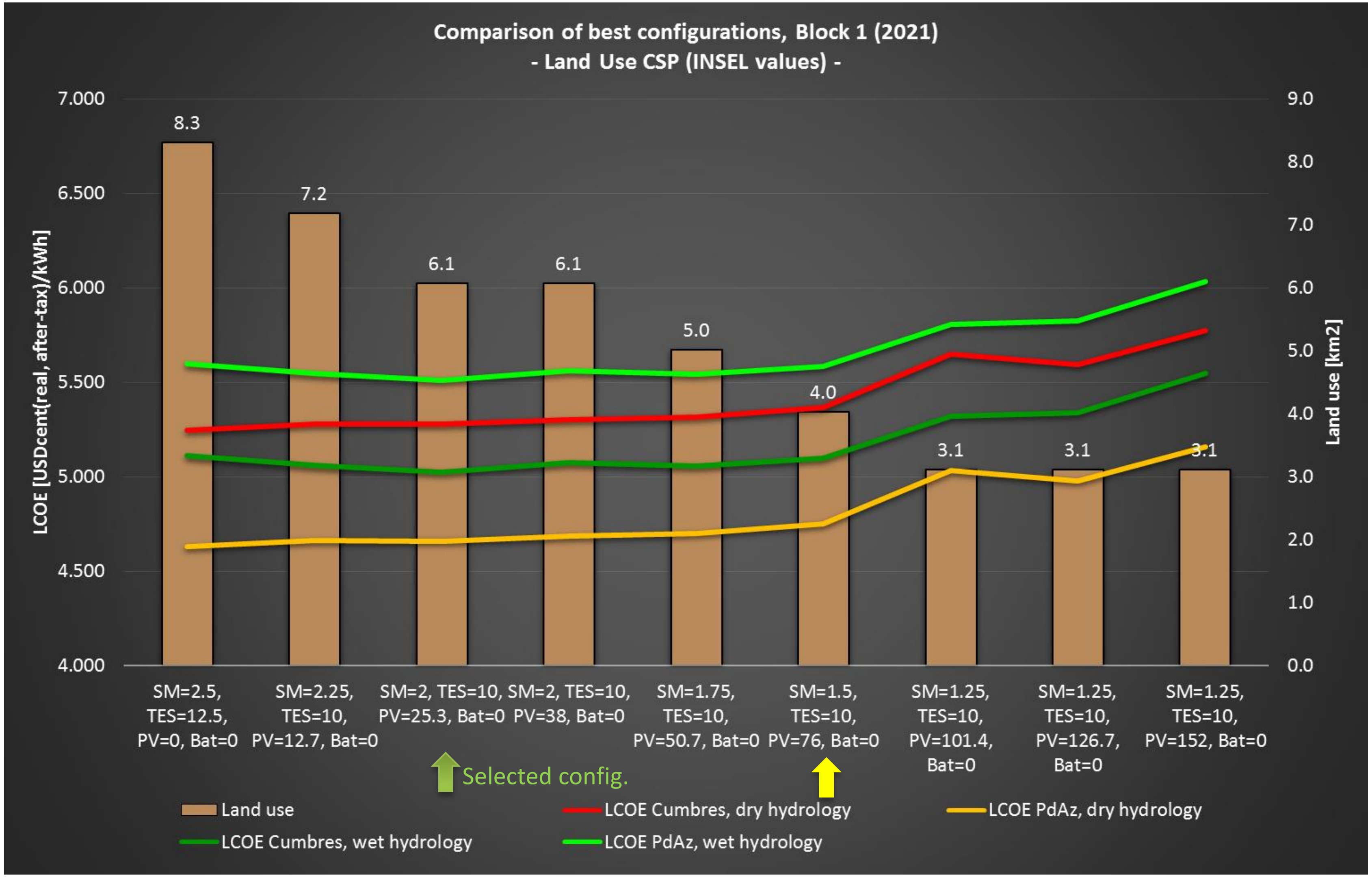
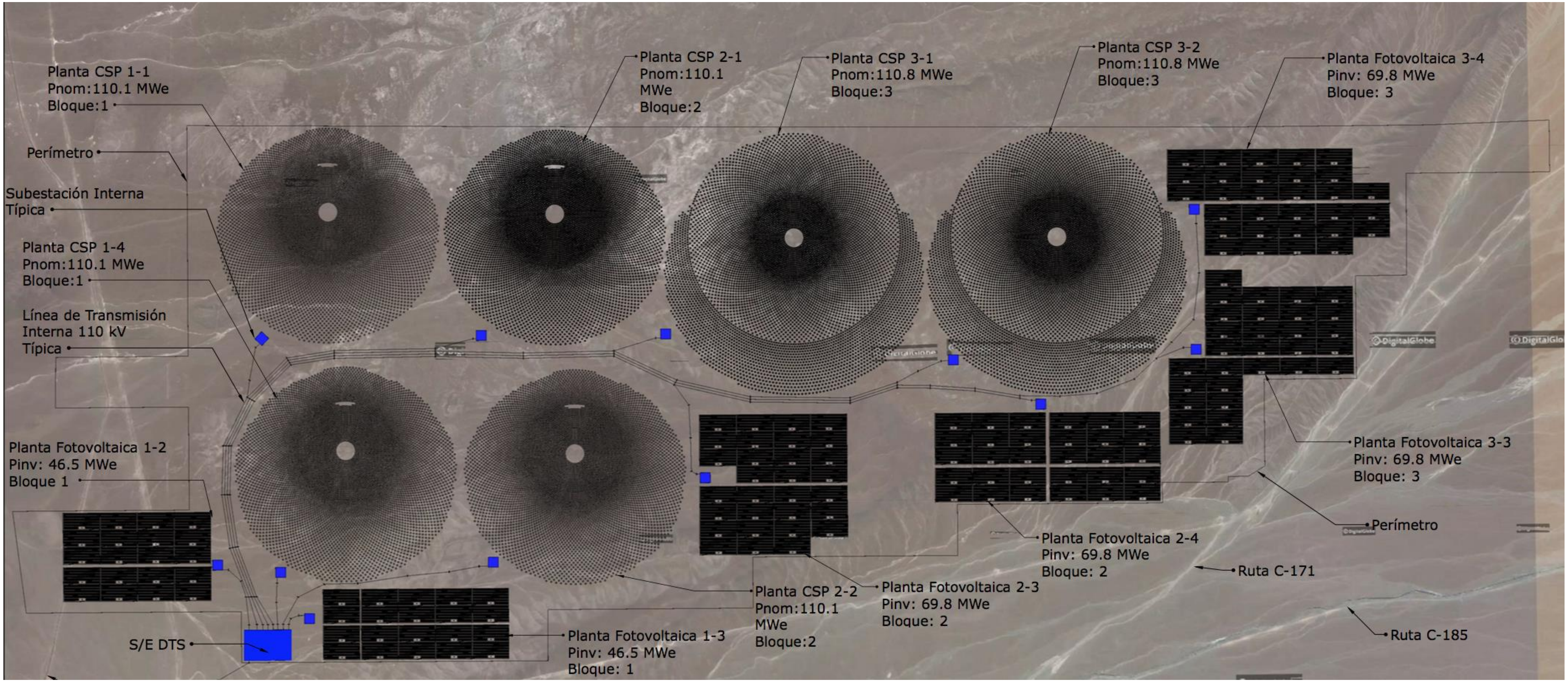
Results



Comparison of best configurations, Block 1 (2021)
- Land Use CSP (INSEL values) -
LCOE [USDcent(real, after-tax)/kWh]
Land use [km2]
7.000
6.500
6.000
5.500
5.000
4.500
4.000
9.0
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
8.3
7.2
6.1
6.1
5.0
4.0
3.1
3.1
3.1
SM=2.5, TES=12.5, PV=0, Bat=0
SM=2.25, TES=10, PV=12.7, Bat=0
SM=2, TES=10, PV=25.3, Bat=0
SM=2, TES=10, PV=38, Bat=0
SM=1.75, TES=10, PV=50.7, Bat=0
SM=1.5, TES=10, PV=76, Bat=0
SM=1.25, TES=10, PV=101.4, Bat=0
SM=1.25, TES=10, PV=126.7, Bat=0
SM=1.25, TES=10, PV=152, Bat=0
Selected config.
Land use
LCOE Cumbres, dry hydrology
LCOE PdAz, dry hydrology
LCOE Cumbres, wet hydrology
LCOE PdAz, wet hydrology

Proposed Plant Layout



Proposed Plant Layout

Parámetros de Diseño	Unidad	Bloque 1 (2021)	Bloque 2 (2023)	Bloque 3 (2025)
Iteración		355	440	446
CSP				
Capacidad Nominal (bruta)	MWe	110.1	110.1	110.8
Capacidad Neta de Salida	MWe	100	100	100
Eficiencia Nominal Turbina	%	42.80%	42.80%	42.80%
Área Total Heliostatos	m^2	851,114	851,114	992,079
Múltiplo Solar	-	1.75	1.75	2
Capacidad TES	MWh_{th}	2,571	3,214	3,235
Capacidad Receptor	MW_{th}	507.8	507.8	584.2
Altura Torre	m	220.8	220.8	229.8
Uso del Terreno CSP	km^2	3.53	3.53	4.34
TES FLH	h	10	12.5	12.5
PV				
Capacidad Nominal (DC)	MWp	50.7	76	76
Capacidad Neta (AC)	MWe	46.5	69.8	69.8
Área Módulos	m^2	245,597	368,395	368,395
Múltiplo Solar	-	1.09	1.09	1.09
Uso del Terreno PV	km^2	1.1	1.65	1.65

Conclusions

- This study focused on searching the technologies that **fit to the bounday conditions in Diego de Almagro**
- It has been demonstrated, that **different combinations** of CSP and PV **lead to similar results** regarding LCOE
- The generation of **dispatchable base load power** supported with power from the grid **is a feasible solution for Chile by combining CSP and PV**
- Further specific conditions need to be considered such as water availability, available land shape, local costs, etc. to select the optimal configuration
- Many of **the available simulation tools do not model an optimal hybridization of CSP and PV**, e.g. considering the coverage of auxiliary electrical consumption of CSP with power from PV or the use of excess electricity as heat in the thermal storage system
- The experience shows that **the hybridization of CSP with PV is gaining importance**, therefore the tools to simulate them need to be improved

THANK YOU
for your attention!

THANKS to my colleagues
for their work and input

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