



SOLAR AND ENERGY
INNOVATION COMMITTEE

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Role of Solar Energy in the National Electric System

Case Study: Chile

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Institutions and Sectors

Chilean Electricity Market



Ministry of Energy

National Energy Commission

Electricity Superintendence

National
Electric
Coordinator
(ISO)



Technical and independent organization.
It is not part of the government administration.

Generation



Private, Free
Energy Prices

Transmission



Private, Regulated
Prices

Distribution



Private, Regulated
Prices

Clients

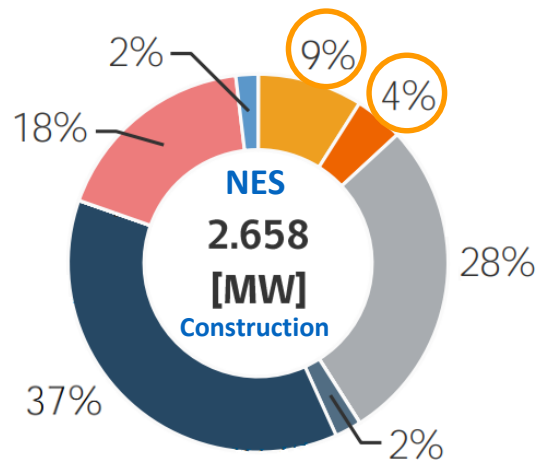
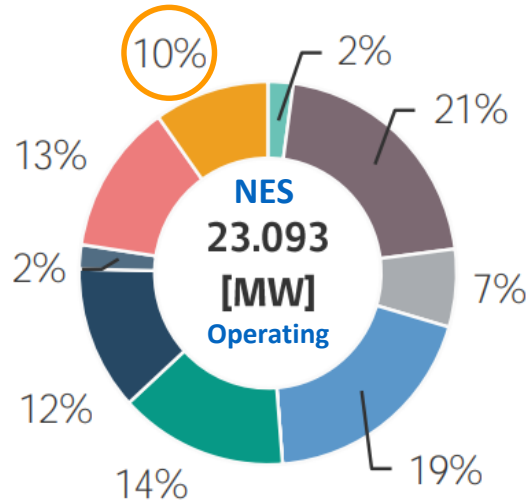


Non-regulated and
Regulated (<5 MW)



National Electric System (NES)

Operating and under construction



Wind



Diesel



Coal



Biomass



Natural Gas



Solar Photovoltaic



Run-of-river



Hydroelectric Dam



Small Run-of-river (< 20 MW)



Geothermal



Concentrated Solar Power (CSP) (*)

To date, the operation of NES has **21%** of NCRE capacity (Non-Conventional Renewable Energies).

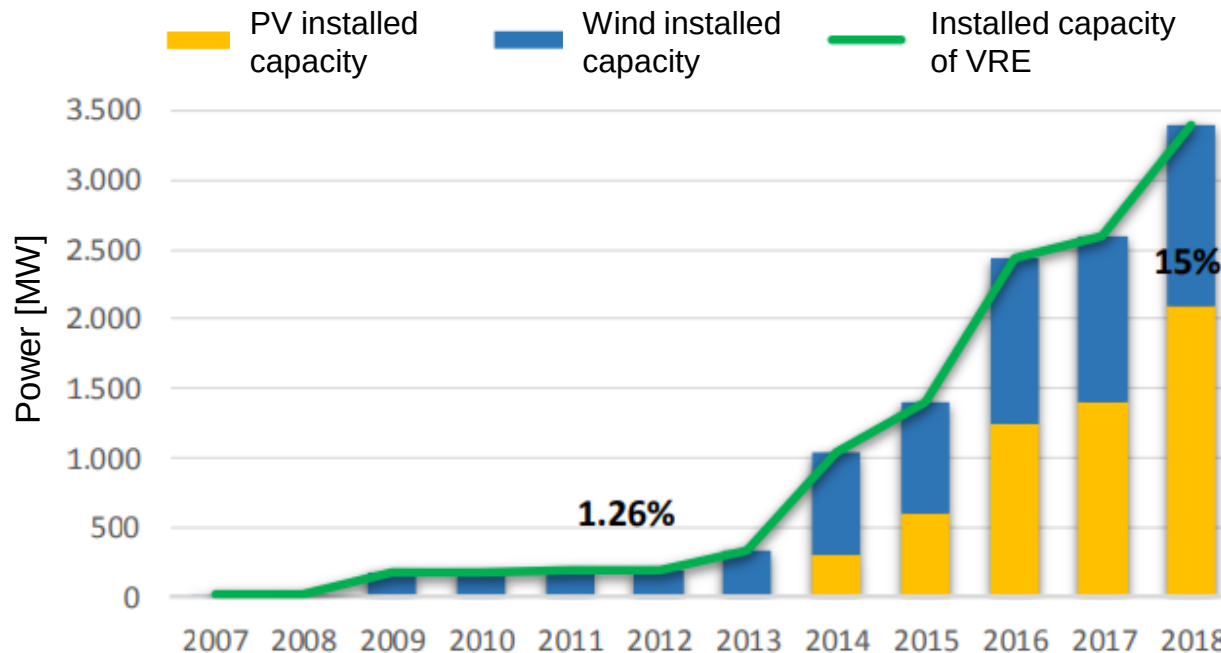
(*) First CSP plant in Latin America.

Source:
National Energy Commission.
National Electric Coordinator (ISO).
December 2018.



National Electric System (NES)

Variable Renewable Energies (VRE)



Source: Systep Ingeniería y Diseños (Chilean consulting company in the energy sector).

- PV plants will be the third generation source in 2019, after coal plants and hydroelectric plants (in 2018 the third place was natural gas plants).
- This will be the first time a Non Conventional Renewable Energy source is in the third place.

Source: National Electric Coordinator (ISO).



National Electric System (NES)

Status of the Electric Matrix

- Considering the NCRE installed capacity in operation, 81% corresponds to variable generation (VRE).
- In relation to the 2,658 MW currently are under construction:

Type	Generation profile / variable cost (VC)	Technology	%
Fossil	Stable, moderate VC indexed at fossil prices	Natural Gas	2
Fossil	Stable (*), high VC indexed at fossil prices	Diesel	18
Renewable	Variable, indexed to renewable resources, low VC	FV, Wind	37
Renewable	Stable, but indexed to hydrological variations, low VC	Run-of-river	39
Renewable	Stable, but indexed to the thermal storage design, low VC	CSP	4

(*) Stable generation profile, but it is rarely dispatched due to its high variable cost.

- Exists a frequent volatility in the price of fossil fuels.
- There is a trend to drier hydrologies.
- The energy stored in reservoirs is currently around 78% of historical levels.



National Electric System (NES)

Status of the Electric Matrix

- The operation of variable generation technologies makes it essential to incorporate technologies that provide "flexibility" in the NES, which is very necessary for a continuous and efficient operation of the electrical system.
- This "flexibility" must include the attribute of "economic dispatch", which will allow having an "economic stability" for the NES.
- The necessary attributes must be established for the generation technologies that will expand the NES in the long term, for a stable and economic operation.

Attributes of Generation Technologies	
Dispatch during the day	Sufficiency and continuity of supply
Dispatch during peak hours	Reduction of greenhouse gases
Dispatch during the night	Availability of primary energy
Economic dispatch (variable cost)	Primary energy cost
Energy storage	Spinning reserve contribution
Inertia contribution	Frequency control contribution
Ramped time to full capacity	Voltage control contribution



National Electric System (NES)

What technologies can provide the required attributes?

→ **Concentrated Solar Power** is an excellent alternative ... Why?

... Because CSP can provide to NES:

- Flexibility → Ability to cope variability and uncertainty of the demand profile.
- Energy storage.
- Versatility → CSP plant can be designed according to the specific demand profile that must be supplied.
- Incorporates stability to the electrical system, providing:
 - Inertia.
 - Spinning reserve.
 - Frequency and voltage control.
- Low variable cost.
- Ramped time to full capacity equal or lower than conventional thermoelectric technologies.
- Renewable generation.
- It can replace coal power plants.
- Exceptional levels of DNI in Chile.

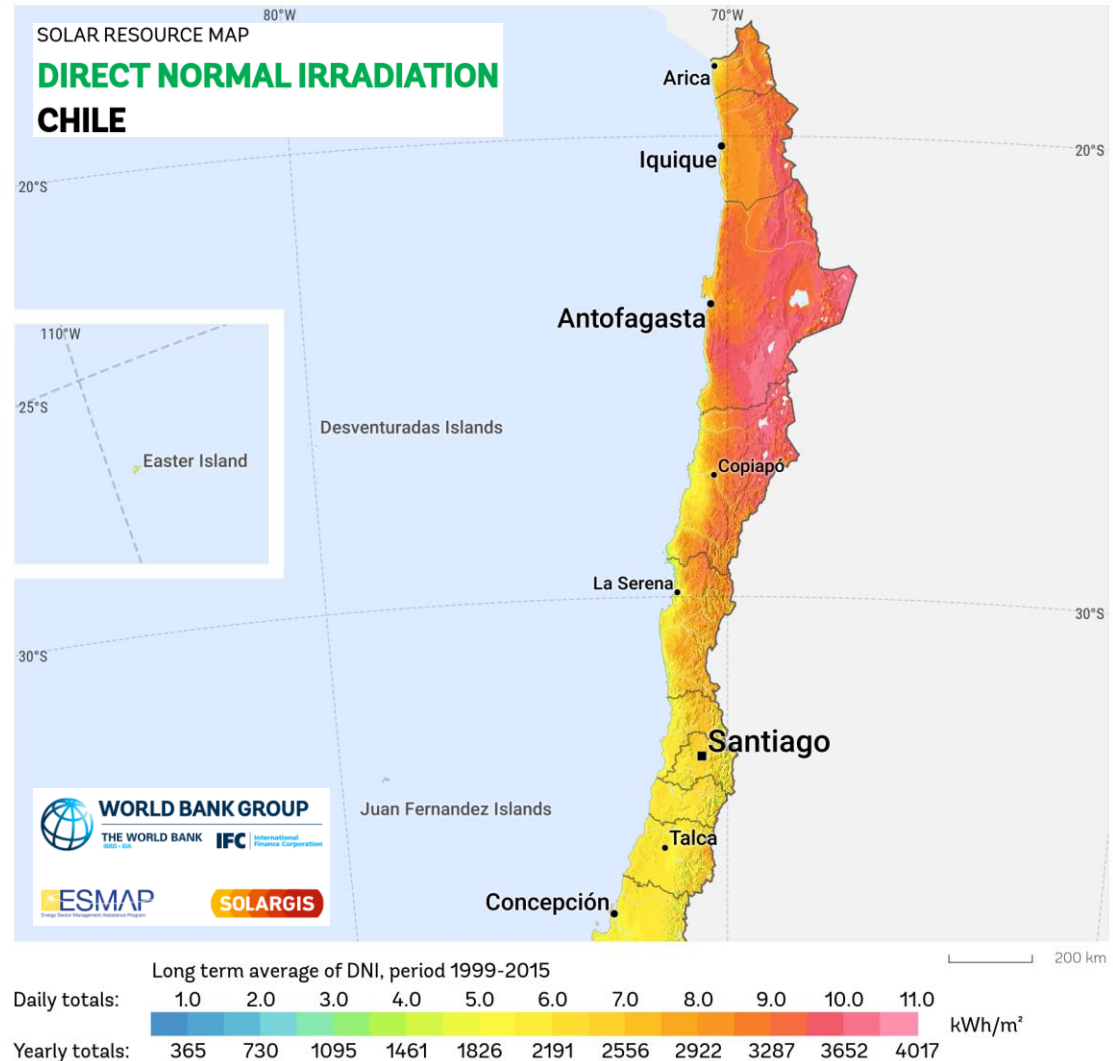


Solar Energy Potential

A great opportunity for Chile

Atacama Desert conditions:

- DNI over $\sim 3,200$ kWh/m² per year (mainly in Antofagasta region).
- Over $\sim 4,000$ hours of sunshine per year.
- Excellent conditions of [atmospheric attenuation](#). There is an exceptional visibility in the Atacama Desert, which usually exceeds 70 km → more efficient operation for CSP tower technology.
- GHI over $\sim 2,400$ kWh/m² per year.
- PVOUT over $\sim 2,200$ kWh/kWp per year.





Decarbonization Plan

Impact on the National Electricity System (NES)

- Currently there are ~ 5 GW of coal plants in operation (27 plants, 67% in the north of Chile).
- Since June 2018 the Ministry of Energy and the 4 companies that own the coal plants are preparing a Decarbonization Plan, which will be announced on the first semester of 2019.
- Decarbonization Plan considers several aspects, such as:
 - Security in the operation of NES.
 - Environmental, labor and social impact.
 - Operating and investment costs in generation and transmission projects.
- The Plan seeks to provide incentives in order that the variable energies can be complemented with other technologies with the attribute of "flexibility", and thus manage the variability.
- In November 2018, the National Electric Coordinator (ISO) made a long-term projection, to determine the impact of the progressive removal of coal plants in the operation of NES.
 - The replacement of coal plants is projected with CSP (mainly), wind, geothermal, run-of-river and hydraulic pumping technologies, since year 2027 onwards.
 - In 2040, approximately 5,000 MW of additional installed capacity will be required.



Operation of CSP Plants

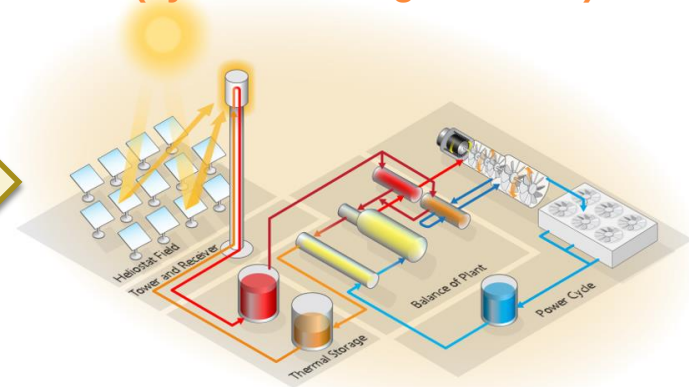
Stability Contribution to NES

Coal Plants (synchronous generation)



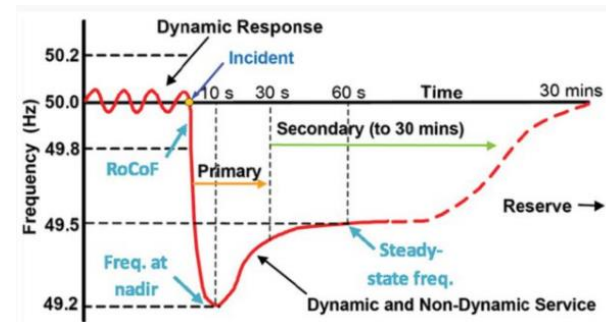
Natural
Replacement in
Chile

CSP Plants (synchronous generation)



- Currently, the **synchronous generation** in NES is provided mainly by coal plants and combined cycle plants.
- That **synchronous generation** can not be replaced with variable generation (Solar PV and Wind power), but it can be replaced through CSP generation with thermal storage.

- The CSP plants can provide inertia to the electrical system.
- This **inertia** is essential to maintain the stability of electricity supply in case of sudden disconnections of transmission lines and/or generating plants.





CSP Projects – Tower technology

Plant Configuration

Plant Configuration	Cerro Dominador (Chile)	NOOR III (Morocco)
Turbine Gross Electric Power [MW-e]	110	150
Efficiency Thermal to Electric	~ 40% - 42%	~ 40% - 42%
Turbine Thermal Power [MW-th]	~ 268	~ 366
Receiver Thermal Power [MW-th]	~ 805	~ 660
Solar Multiple	~ 3,0	~ 1,8
Thermal Energy Storage (TES) [hours]	17,5	7,5
Quantity of Heliostats	10.600	7.400
Reflective surface [m ²]	~ 1.484.000	~ 1.300.000
Direct Normal Irradiance (DNI) [kWh/(m² año)]	~ 3.700	~ 2.500

Source: NREL, SENER Molten Salt Tower Technology (Ouarzazate NOOR III case) and own elaboration.

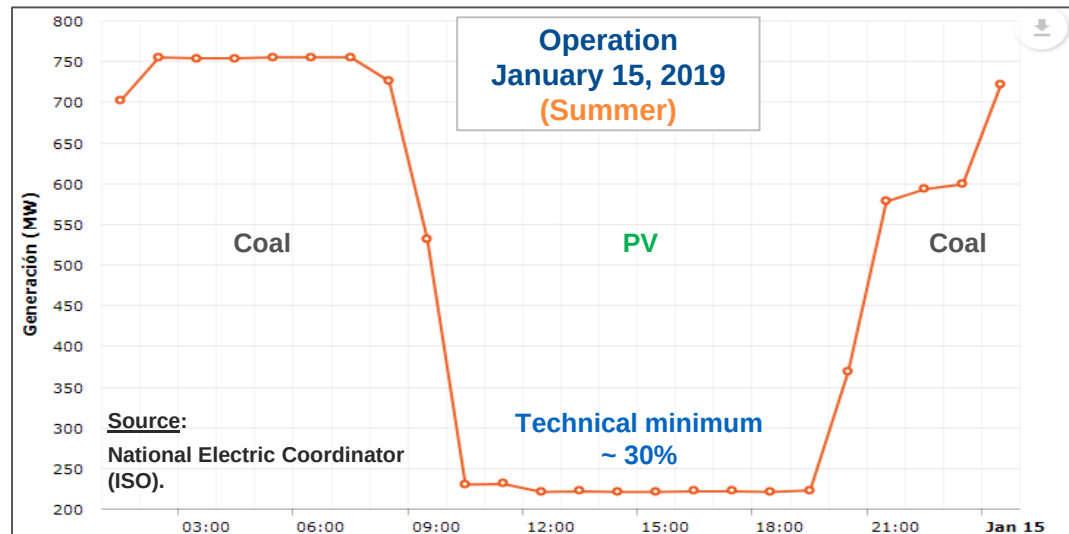
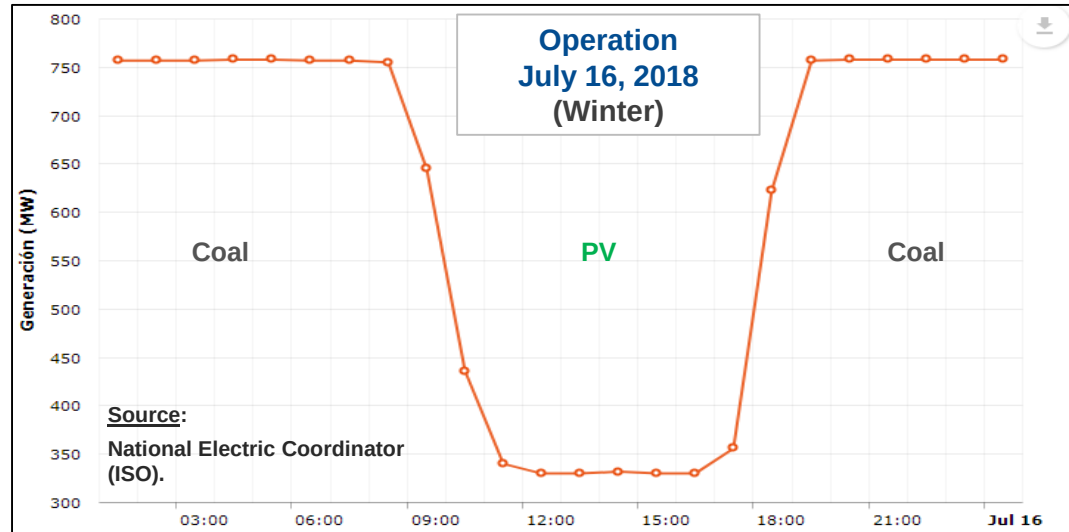
→ CSP is an "*speciality*" technology, designed according the load profile required.



Operation of Coal Plants in Chile

Reference: Guacolda Coal Plant 760 MW

- Before the start in operation of the large-scale PV plants, the coal plants supplied the "base load", required mainly for industrial operations.
- With the current operation of PV plants, some coal plants have a very different operating profile than "base load".
- Considering that CSP plants are the natural replacement of coal plants in Chile, CSP projects should have the suitable configuration to complement PV generation:
CSP configuration (reference):
 - Solar Multiple ~ 2.3
 - TES ~ 13 hours.

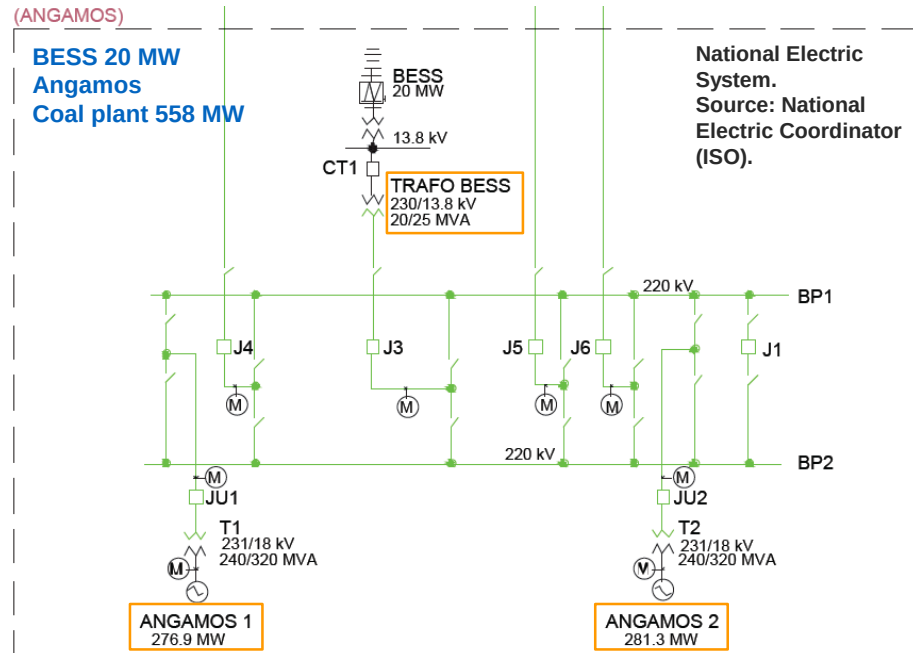




Energy Storage Systems (BESS)

National Electric System (NES)

- There are electrochemical storage systems with lithium-ion batteries in operation:
 - BESS 20 MW, next to Angamos coal plant of 558 MW.
 - BESS 20 MW, next to Cochrane coal plant of 548 MW.
 - BESS 12 MW, next to Los Andes electrical substation.



- The BESS facilities have been used especially at critical moments to stabilize the frequency of the electrical system, achieving a very good response and precision in frequency control, during short periods.
- Also, lithium battery systems will be installed in run-of-river plants, in order to provide regulation capacity, stability and flexibility to the electrical system.

BESS: Battery Energy Storage Systems.



Final Comments

- For planning the expansion of the electrical system in the medium and long term, it is not enough to think only about incorporating more installed capacity and more generation.
- It is necessary to differentiate the attributes of generation technologies, due to each technology has different features for the electrical system.
- In this sense, it is essential to incorporate synchronous technologies in the expansion of the electrical system, to complement the growing implementation of variable generation technologies (such as PV and Wind power).
- The CSP plants, and their various alternative configurations, can provide synchronous generation and all the attributes of the coal plants that will be progressively closed. In this way the electrical system will be able to maintain stability, flexibility and economic dispatch required.
- To encourage investment in synchronous and flexible technologies, must be defined clearly the payment mechanisms for these benefits, in order to maintain the stability in the operation of the electrical system.



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Thank you

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