Fraunhofer
CHILE

Large Scale PV: The Chilean Experience

INTERSOLAR | SOUTH AMERICA
SAO PAULO, BRAZIL, AUGUST 2016

Fraunhofer Chile Research – Center for Solar Energy Technology | FCR-CSET

August 24, 2016

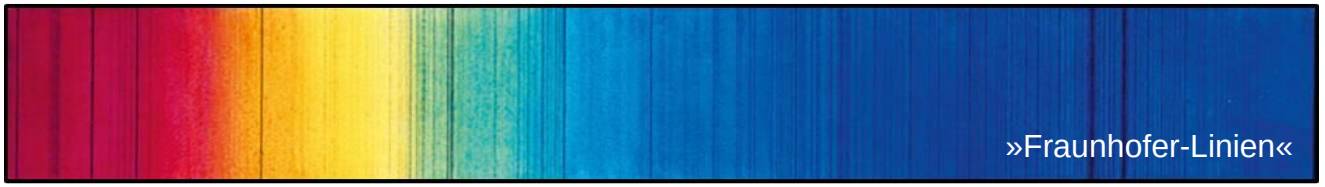
LARGE SCALE PV: THE CHILEAN EXPERIENCE

- Fraunhofer : General Introduction
- Electrical Market in Chile
- Evolution of Large Scale Solar PV in Chile
- Analysis of the Chilean Experience: Opportunities and Challenges
- How are we facing this challenges
- Long term view

The Fraunhofer-Gesellschaft

Largest Organization for Applied Research in Europe

- 67 institutes and research units / Based in Germany
- Staff of more than 23,000
- €2 billion annual research budget totaling
  - Roughly two thirds of this sum is generated through contract research on behalf of industry and publicly funded research projects
  - Roughly one third is contributed by the German federal and state governments in the form of base funding
- International co-operations
- In Chile since 2010 (Biotechnology Center)
- Fraunhofer CSET – Solar Energy Center – In operation since Feb 2015
  - Pontificia Universidad Catolica de Chile: Coexecutor
  - Project co-funded by the Chilean Government

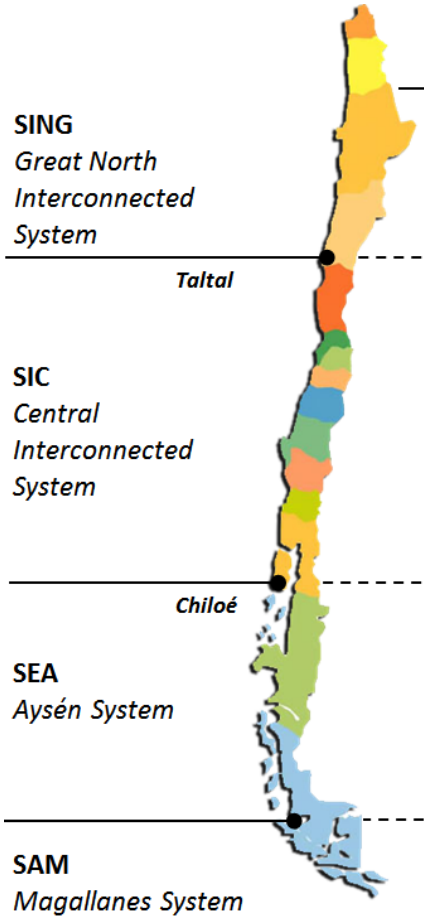


SOLAR ENERGY IN CHILE

Enormous potential – high challenges

- Up to 3.400 kWh/m² global horizontal irradiation per year
- North of Chile has the potential to supply all of Chile with clean solar electricity + even export electricity to neighboring countries
- Challenges: high UV, high temperature gradients, dust, salts, water scarcity,…
- Grid integration: Electricity storage and transport technologies will be important
- R&D on „high radiation solar“ needed
  → opportunity for Chile
- Increase local contents, local jobs
- Reduce costs

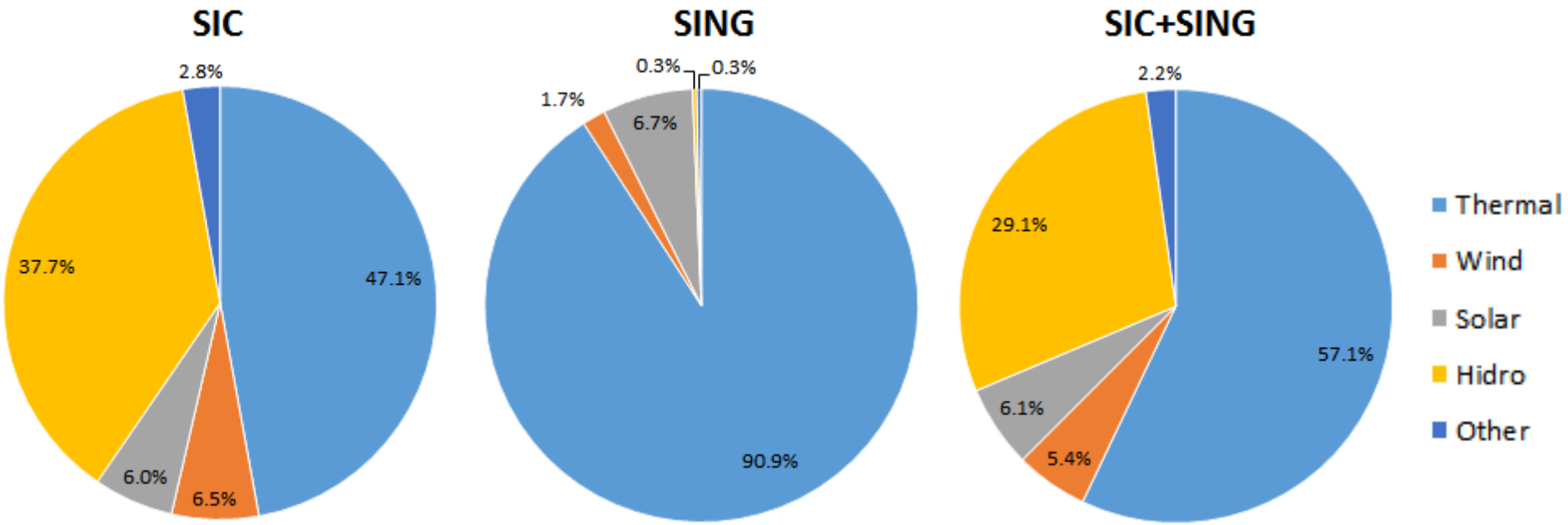
SOLAR ENERGY IN CHILE:
CHILE'S MAIN POWER SYSTEMS



	Gross Capacity (Aug.-2016)	Electric Production (2015)	Maximum Demand (2015)	Population
SING *Great North Interconnected System*	**4,300 MW** **878 MW testing** *20.3 %*	**18,731 GWh** *26.0 %*	**2,555 MW**	**6.3 %**
Taltal				
SIC *Central Interconnected System*	**16,740 MW** **818 MW testing** *78,9 %*	**52,901 GWh** *73.4 %*	**7,789 MW**	**92.2 %**
Chiloé				
SEA *Aysén System*	**63 MW** *0.3 %*	**137.06 GWh** *0.19 %*	**22.6 MW**	**0.6 %**
SAM *Magallanes System*	**114 MW** *0.54 %*	**306.5 GWh** *0.43 %*	**52,8 MW**	**0.9 %**

Elaboración propia. Fuente: CNE, CDECs

SOLAR ENERGY IN CHILE:
ENERGY MATRIX COMPOSITION (CAPACITY)

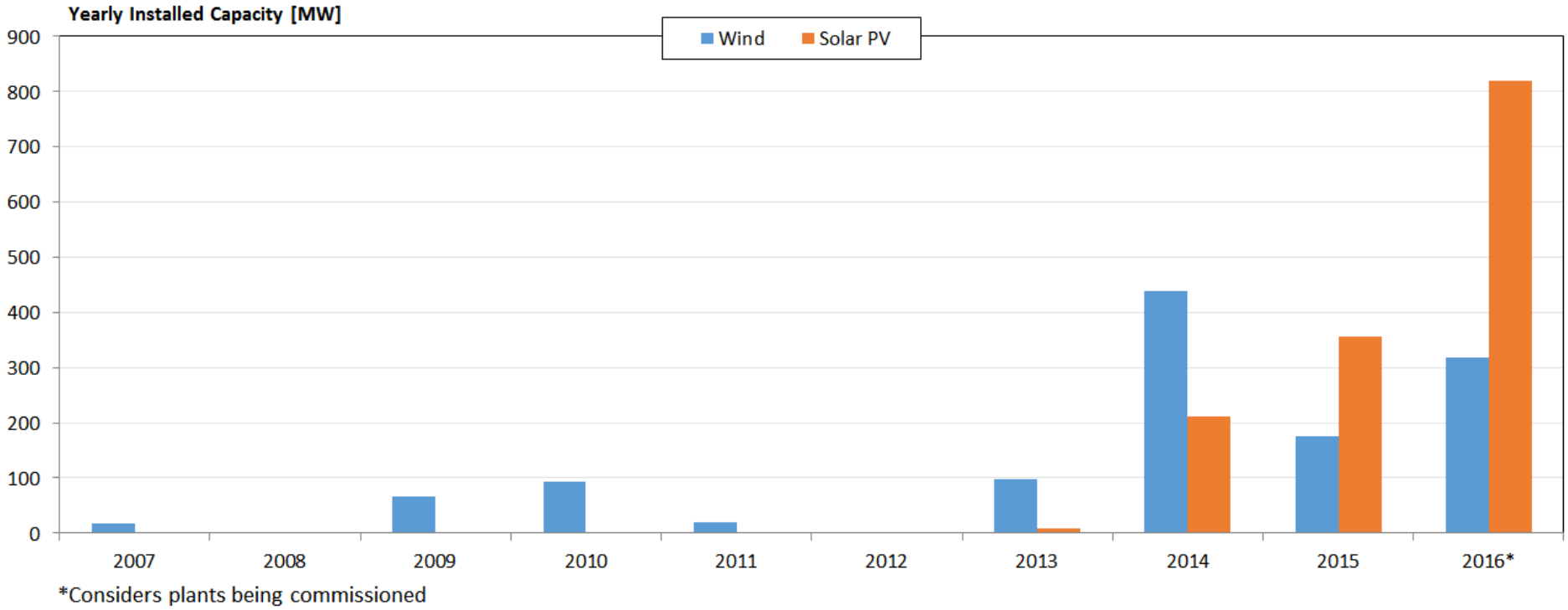


Central - South

North

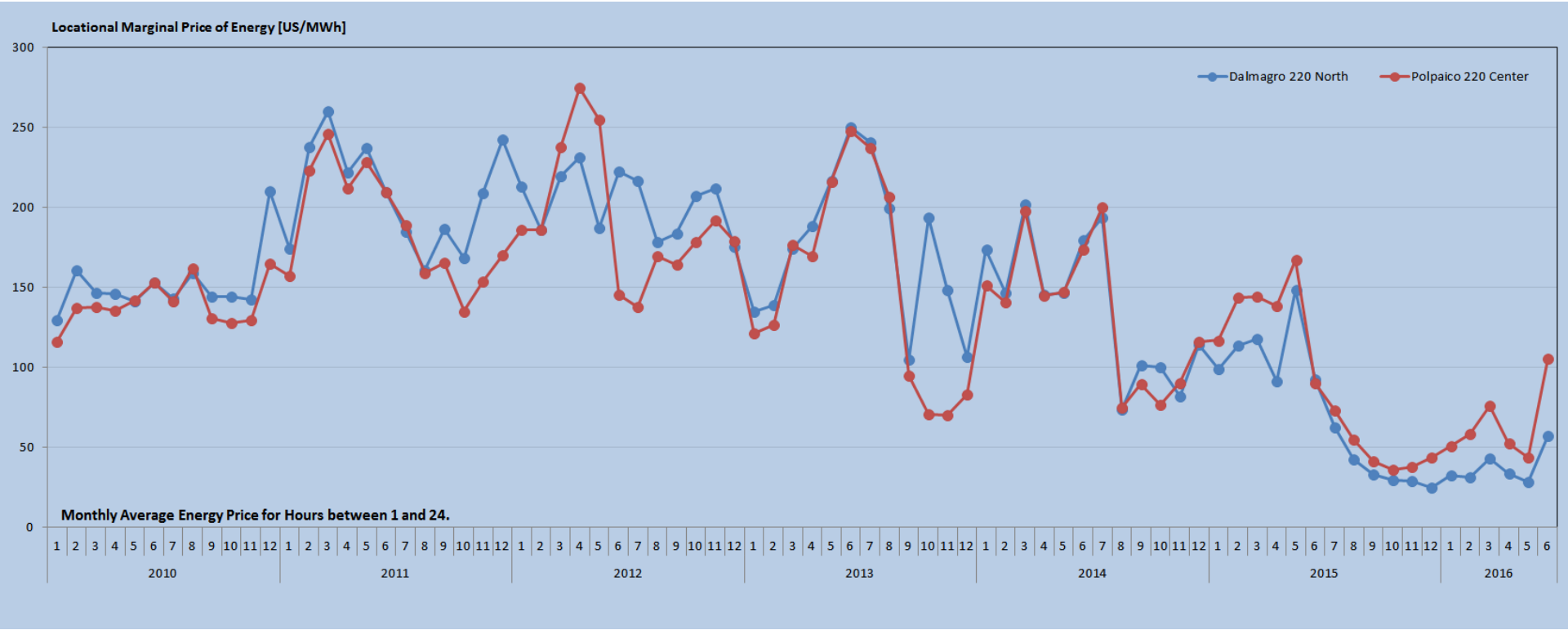
Elaboración propia. Fuente: CNE, CDECs. Febrero 2016

RENEWABLE ENERGY IN CHILE:
RENEWABLE INSTALLED CAPACITY DEPLOYMENT IN CHILE



Elaboración propia: Fuente CNE,
CDEC-SIC y Licitaciones Eléctricas.

SOLAR ENERGY IN CHILE:
SPOT MARKET ENERGY PRICE EVOLUTION



Elaboración propia: Fuente CDEC-SIC.

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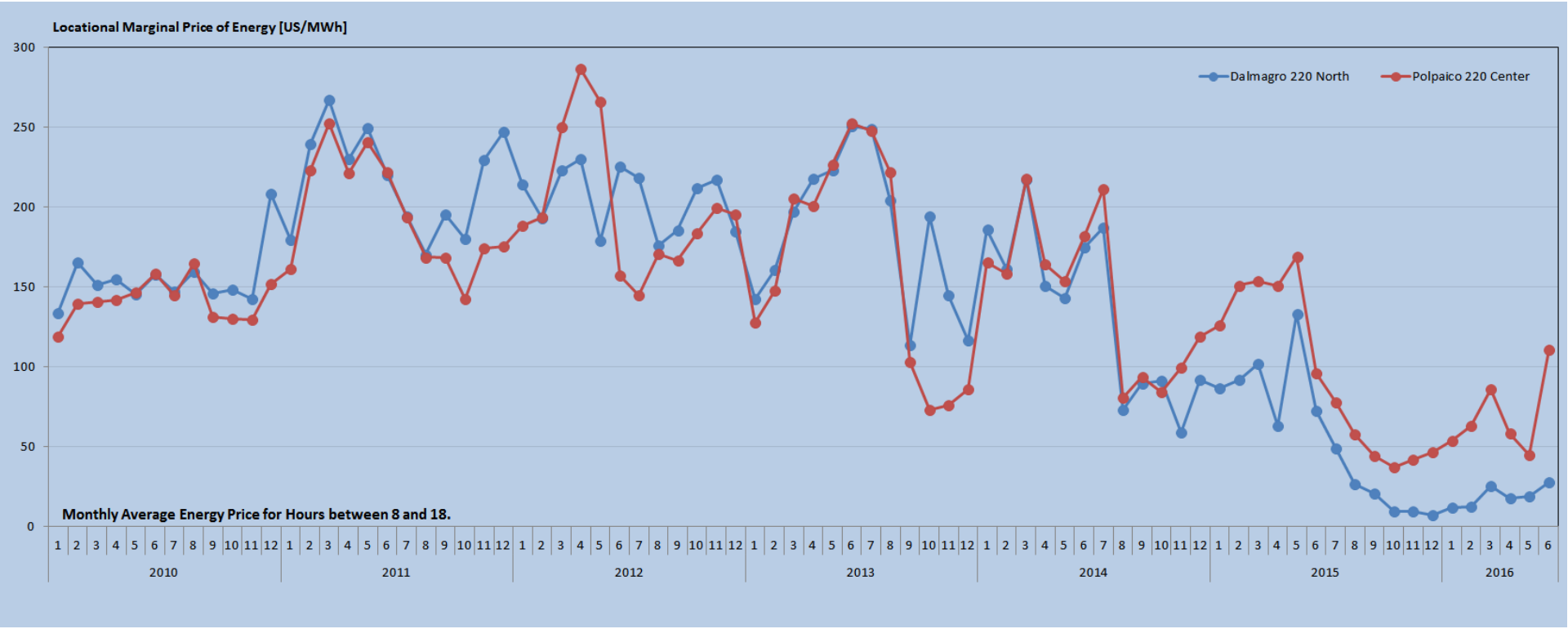

Elaboración propia: Fuente CDEC-SIC.

SOLAR ENERGY IN CHILE:
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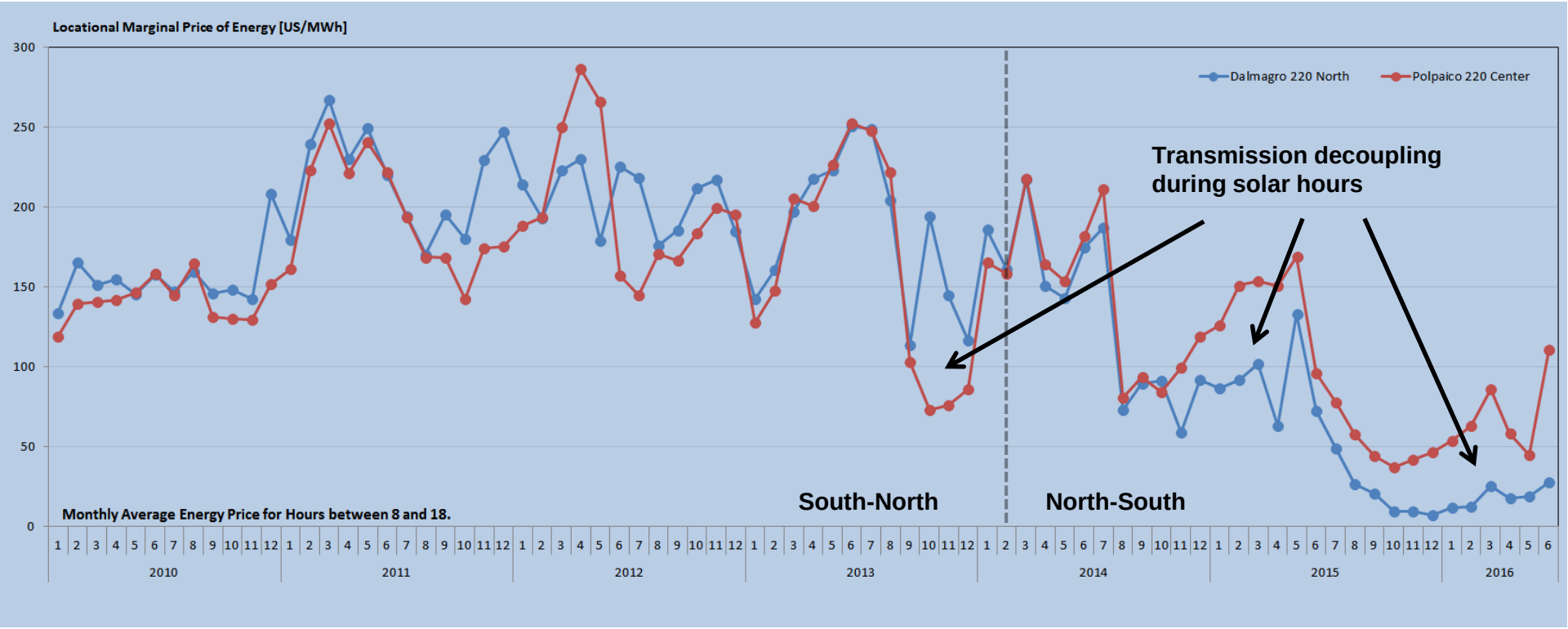
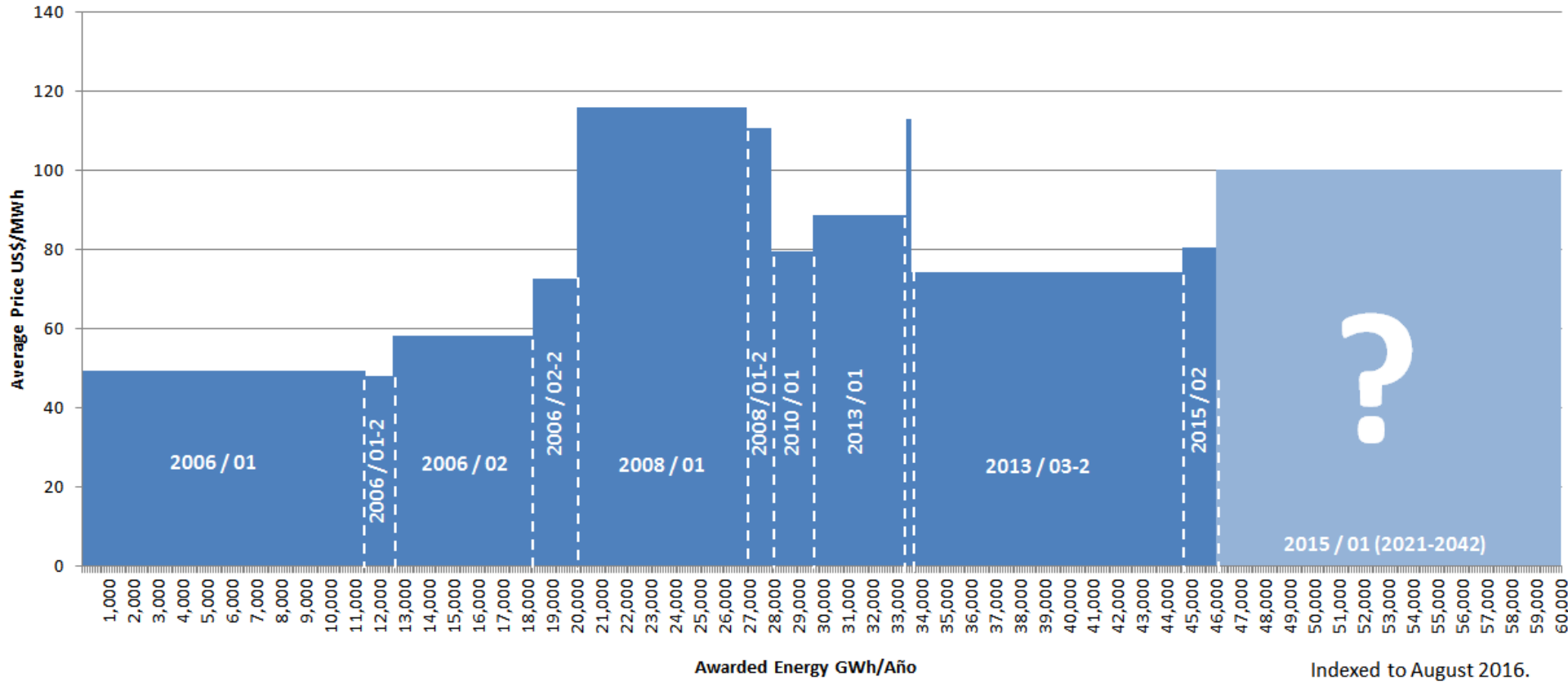


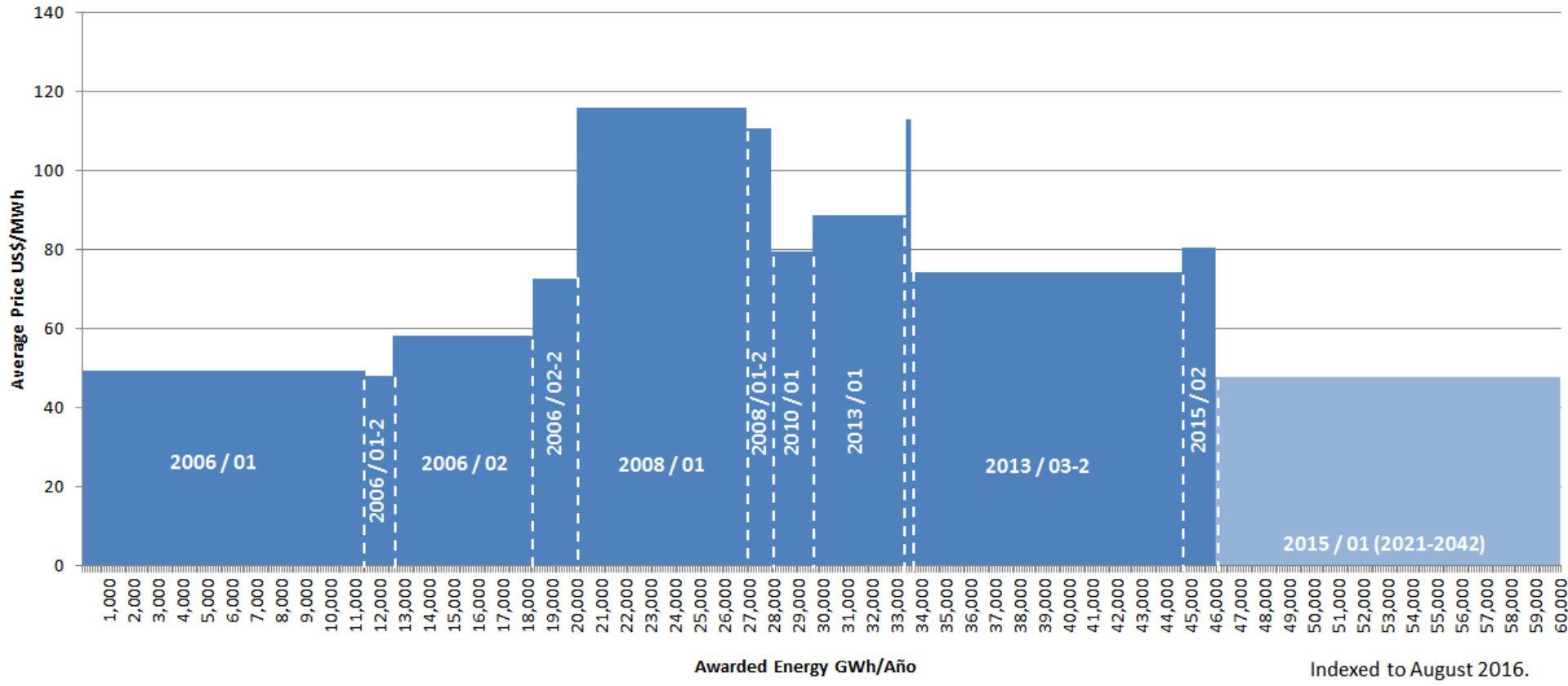
Elaboración propia: Fuente CDEC-SIC.

LAST ENERGY AUCTIONS IN CHILE



Indexed to August 2016.

LAST ENERGY AUCTIONS IN CHILE



Indexed to August 2016.

LAST [illegible] CHILE

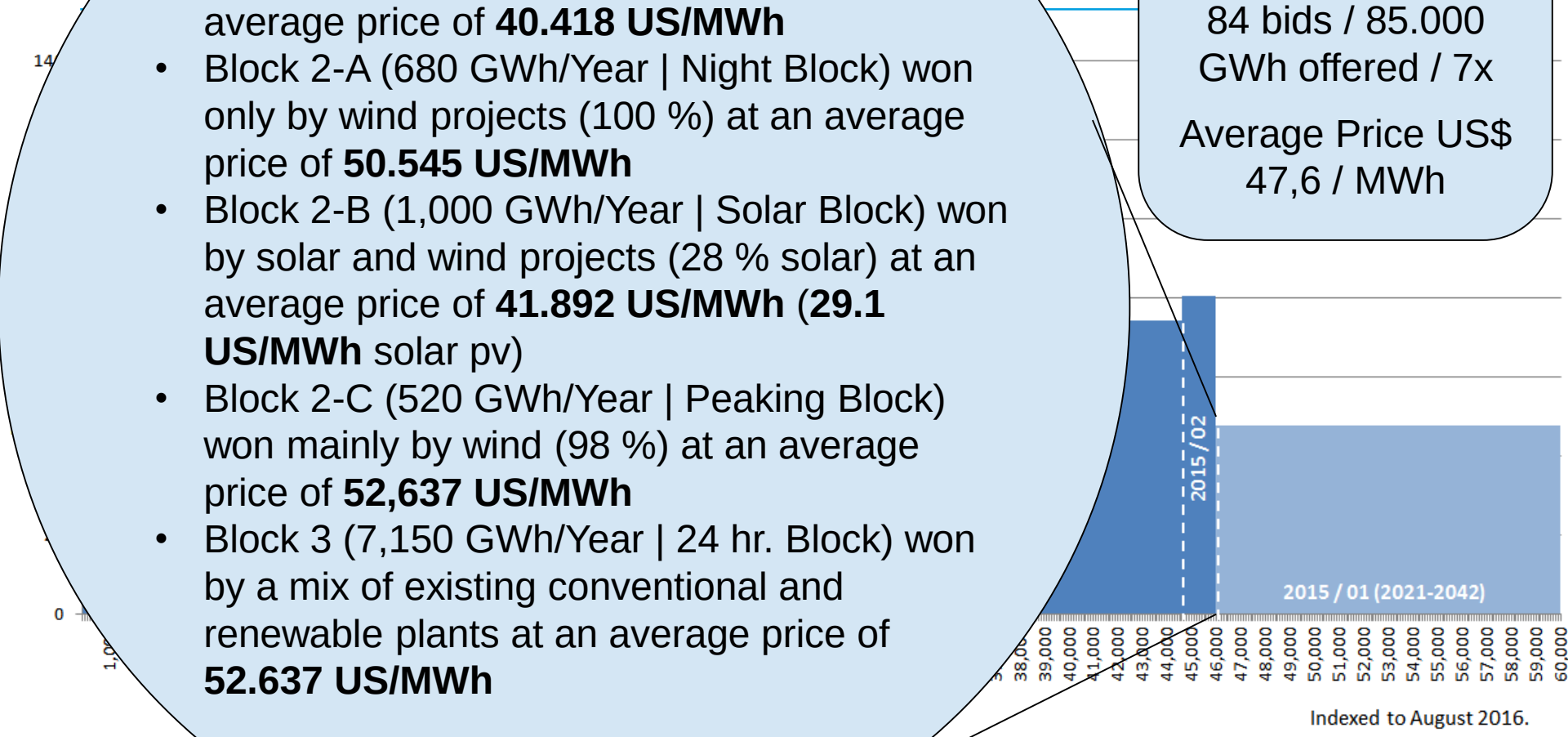
- Block 1 (3,080 GWh/Year | 24 hr. Block) won mainly by wind projects (94.7 %) at an average price of **40.418 US/MWh**
- Block 2-A (680 GWh/Year | Night Block) won only by wind projects (100 %) at an average price of **50.545 US/MWh**
- Block 2-B (1,000 GWh/Year | Solar Block) won by solar and wind projects (28 % solar) at an average price of **41.892 US/MWh** (**29.1 US/MWh** solar pv)
- Block 2-C (520 GWh/Year | Peaking Block) won mainly by wind (98 %) at an average price of **52,637 US/MWh**
- Block 3 (7,150 GWh/Year | 24 hr. Block) won by a mix of existing conventional and renewable plants at an average price of **52.637 US/MWh**

12.430 GWh/year

Supply 2021 onwards

84 bids / 85.000 GWh offered / 7x

Average Price US$ 47,6 / MWh



THE NEW DESERT LANDSCAPE IN CHILE…

Planta PV El Salvador
El Salvador, Chile
70 MW

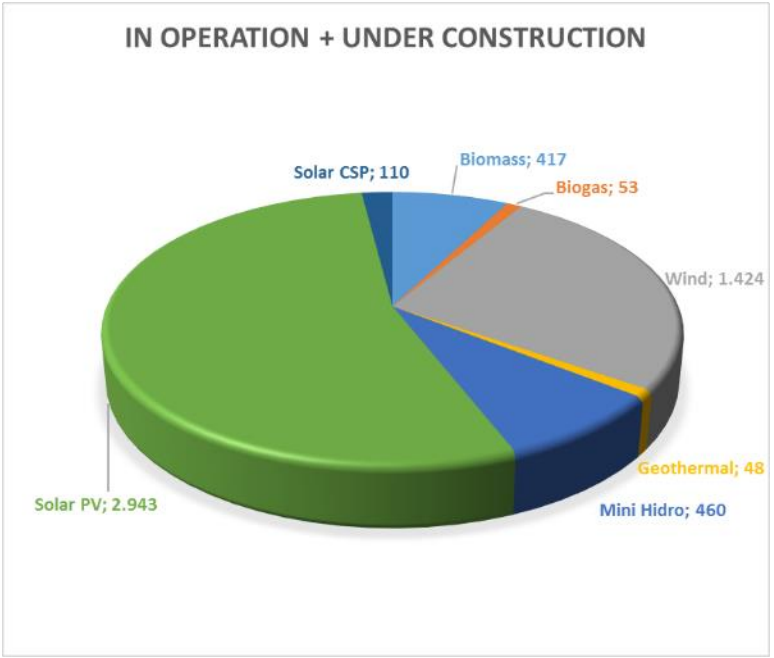
NEW NEIGHBORS IN DIEGO DE ALMAGRO (900 KM NORTH OF SANTIAGO)

RENEWABLE ENERGY SITUATION IN CHILE – JULY 2016

Renewable Energy Status - July 2016

Technology	In Operation (MW)	Under Construction (MW)	Approved (MW)	Under Approval Process (MW)
Biomass	417	0	112	67
Biogas	53	0	8	0
Wind	947	477	6.500	1.949
Geothermal	0	48	120	0
Mini Hidro	435	25	455	95
Solar PV	1.267	1.676	12.038	5.434
Solar CSP	0	110	1.085	1.270
TOTAL	**3.119**	**2.336**	**20.318**	**8.815**

Source: CNE, SEIA, CDEC-SIC, CDEC-SING, CIFES



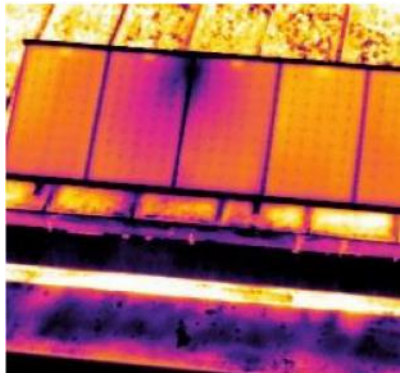
Total Renewable Energy installed capacity: 2.550 MW (12,65% of total capacity)
88,5% of Renewable Energy connected to the SIC
Total Energy injected to the grid from renewable sources: 670 GWh during July 2016 (10,82% of the total generation)

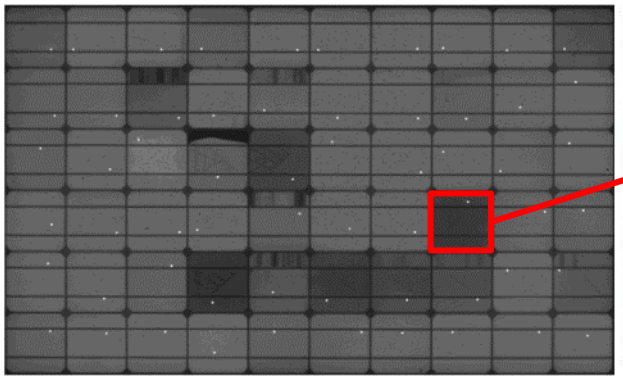
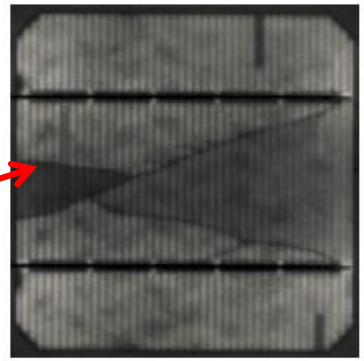
CHALLENGES

- Transmission issues
- Soiling / Dust
- Quality / Components / High UV
- Energy dispatch issues
- Local content
- New Transmission Law / More Transmission Capacity
- Monitoring / Cleaning techniques
- Testing / Tech. Adaptation
- Forecasting systems
- National Strategic Program

Quality of components in outdoor extreme conditions

Degradation analysis: Thermography (IR) and Electroluminescence (EL)

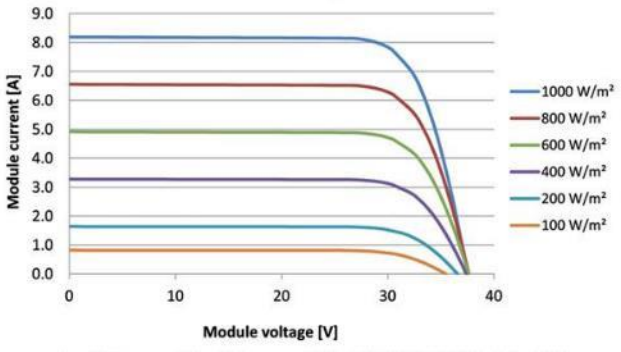


- Most common failures in PV modules are visible true EL and IR
  - Infrared inspection → hot spots are visible
  - Localized EL inspection → failures become visible
  - Early failure detection → anticipate degradation of system and activate product warranties
  - Common failures: micro cracks due to transportation & fabrication issues

Monitoring Laboratory

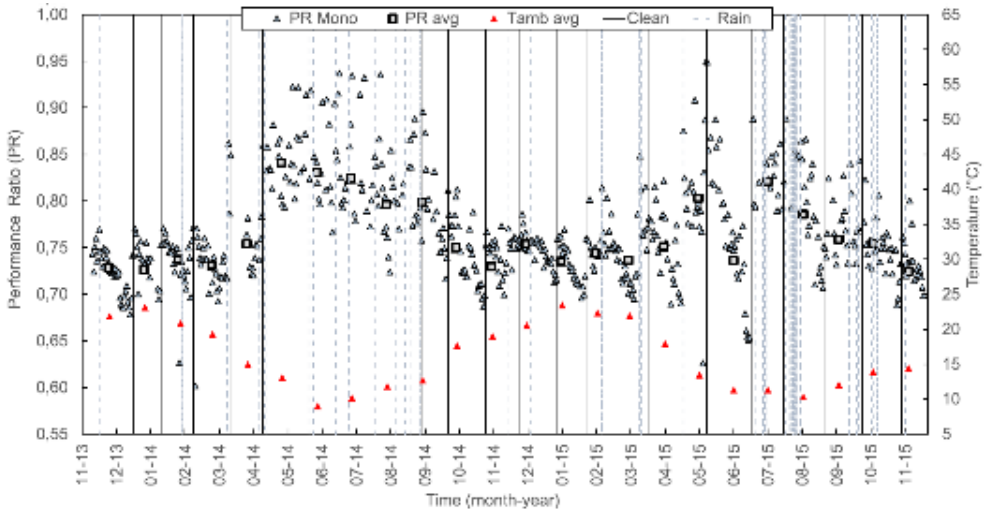
testing of different technologies



- Laboratory for testing current and new technologies
- Analysis of performance, power generation profiling of bifacial technology
- Automated tracer of I-V characteristics and meteorological data of PV panels
- Determination of temperature coefficient of technologies for arid areas
- Validation of anti-soiling products or cleaning robots

Analyzing Soiling Losses for industrial PV plants

most common losses in Atacama Desert



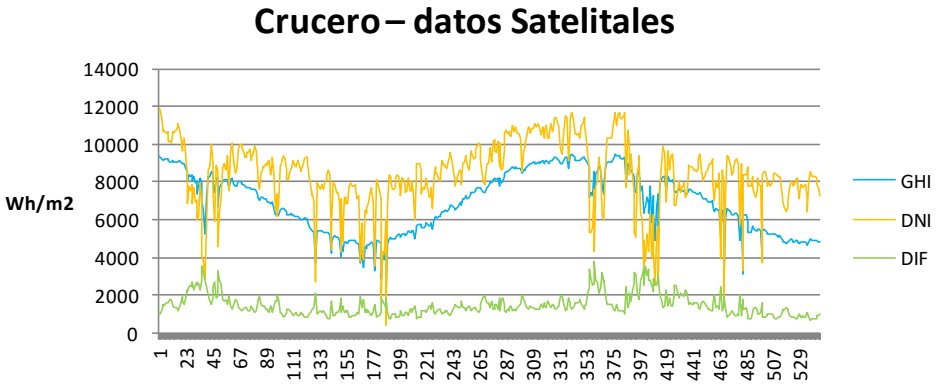
- Soiling losses can strongly impact the generation of PV plants with up to 30% loss
  - We analyze each plant locally, since soiling strongly depends on climate
  - Through a mobile lab we characterize PV systems directly on place of installation
- Real data can be generated on the detrimental issues of soiling in the region
  - We can determine cleaning procedures and give input to local fabricants
  - Modeling of soiling losses give insights on cleaning procedures / soiling mitigation

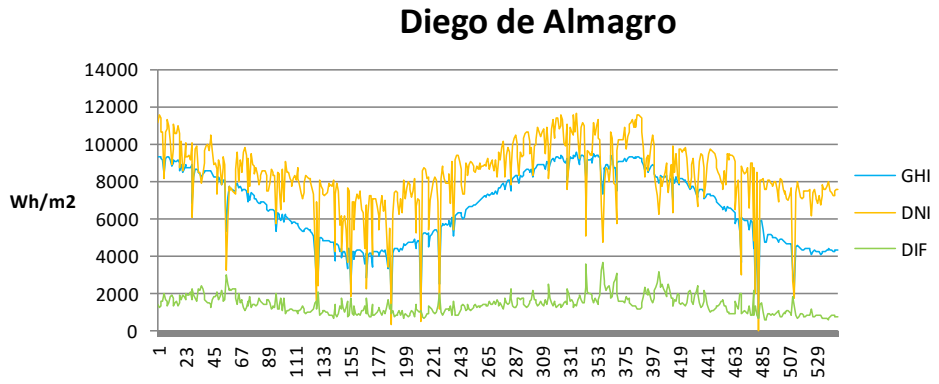
Ref: *Urrejola et al. Energy Conversion and Management 114 (2016) 338–347

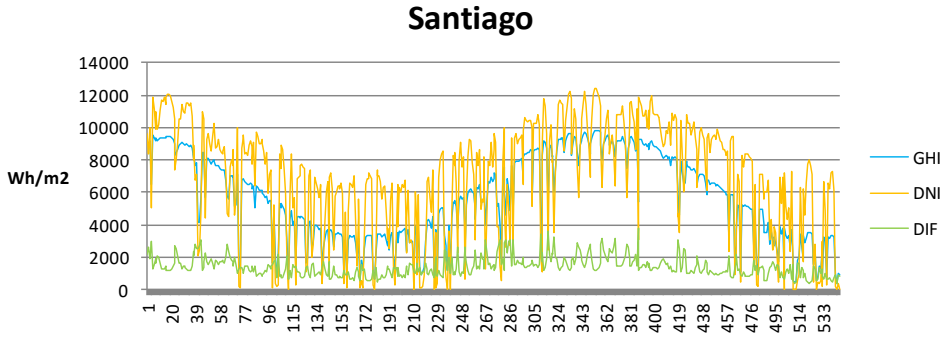
Variability

Daily irradiation variability, ~annual period, (Global, DNI and Diffuse) in Wh/m2 2011-2012

- Almost every day has some clouds in Chile
- Time variability is relatively high during all the year
- Maximum radiation levels are similar in Northern and Central Chile.
- Total anual radiation (DNI) are the highest worldwide, given the number of clear days and sustained daily max levels.





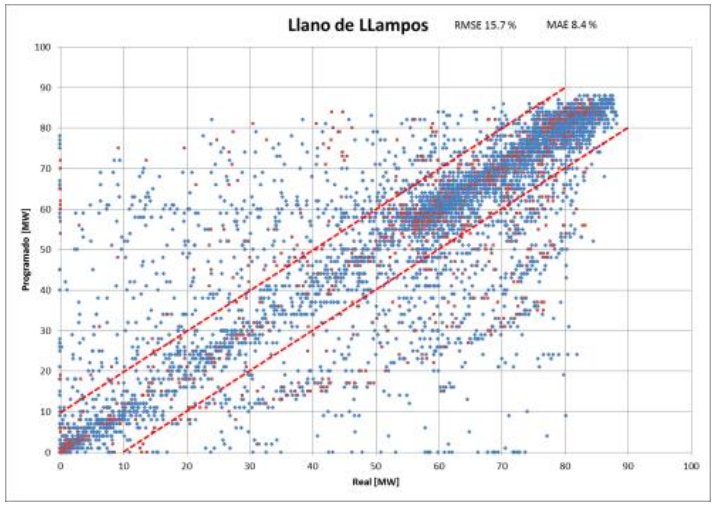


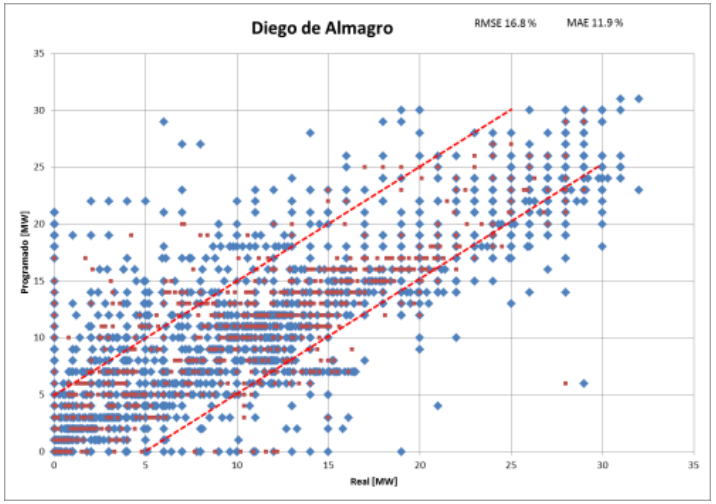
Source: R. Escobar / Fraunhofer CSET / PUC

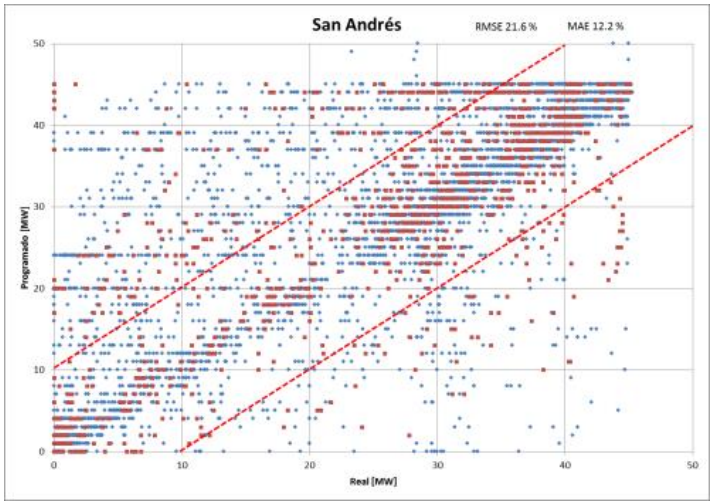
There are clouds in the Atacama Desert…

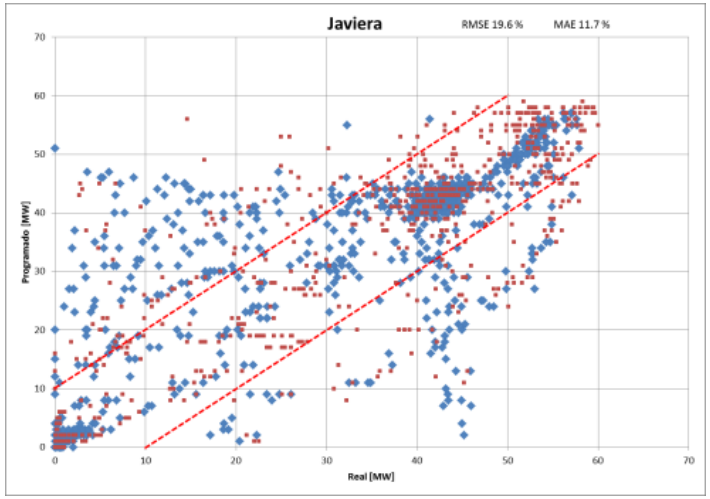
Source: R. Escobar / Fraunhofer CSET / PUC

Impact in PV Production – Real Examples / SIC



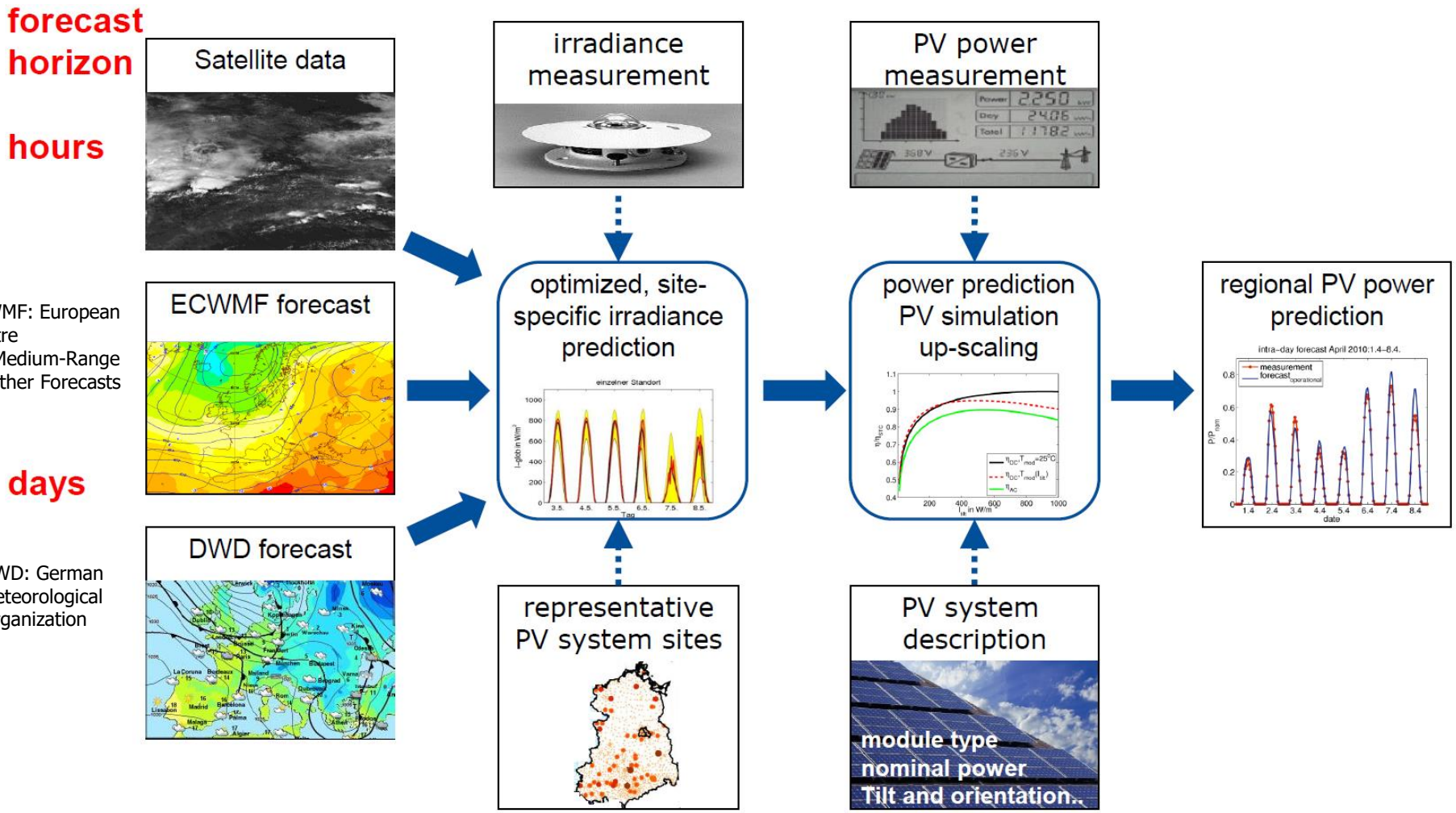






CDEC-SIC
Info
Study by Gonzalo Ramirez and Rodrigo Escobar, FCR-CSET, 2015

Technological Options Available Today – Forecasting Methodologies



Source: R. Escobar / Fraunhofer CSET / PUC

Forecasting – Nowcasting – Solar Energy Production

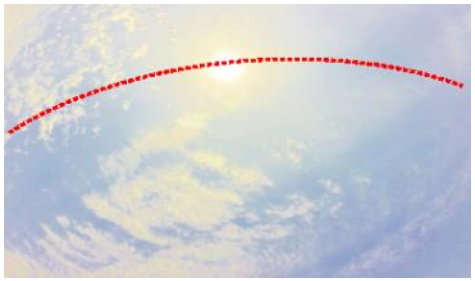
Solar & Power Forecasting (Nowcasting)

- Short term solar production prediction (1-48 hrs.)

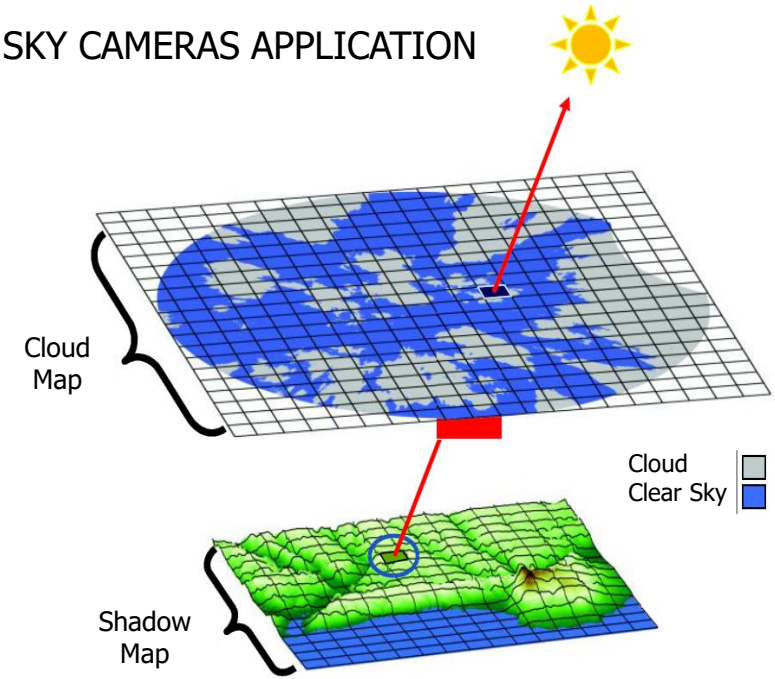
State of the art of power forecasting on photovoltaics

J. Antonanzas[a,*], N. Osorio[b], R. Escobar[b,c], R. Urraca[a], F.J. Martinez-de-Pison[a], F. Antonanzas-Torres[a]

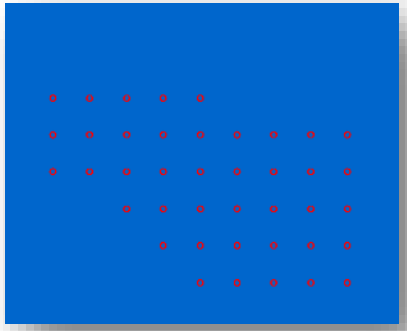
[a]EDMANS Group, Department of Mechanical Engineering, University of La Rioja, Logroño, Spain.
[b]Center for Solar Energy Technologies, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile
[c]Pontificia Universidad Católica de Chile, Av. Vicuña Mackenna 4860, Macul, Santiago, Chile



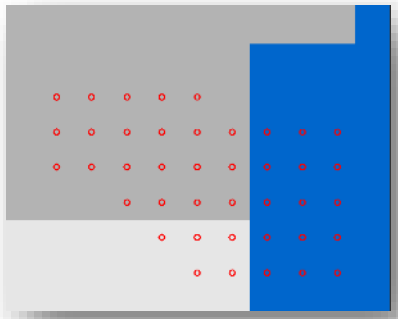
SKY CAMERAS APPLICATION



Clear Sky



Partially Clouded Sky



Source: R. Escobar / C. Cortés / Fraunhofer CSET / PUC

PES – National Solar Strategic Program
Objective: Increase Creation of Local Value

PROGRAMA ESTRATÉGICO SOLAR

STRATEGIC SOLAR PROGRAM
ROAD MAP GUIDELINES

INDUSTRIAL DEVELOPMENT	HUMAN CAPITAL DEVELOPMENT	TECHNOLOGICAL DEVELOPMENT	STRENGTHENING QUALITY INFRASTRUCTURE
• Open innovation platform • Solar suppliers development program • High-tech investment attraction program	• Drafting of labor skills profiles • Training • Certification • Advanced Human Capital program	• Desert module and system technology program • Solar mining and metallurgy program • Thermal energy storage systems program • Solar desalinization program • Solar fuels program	• Climate characterization • Regulations and standards • Conformity assessment schemes • Metrology network

Solar technology center

Solar technology districts

Technological Development Program
Closes November 15

FINANCING
2016 - 2025

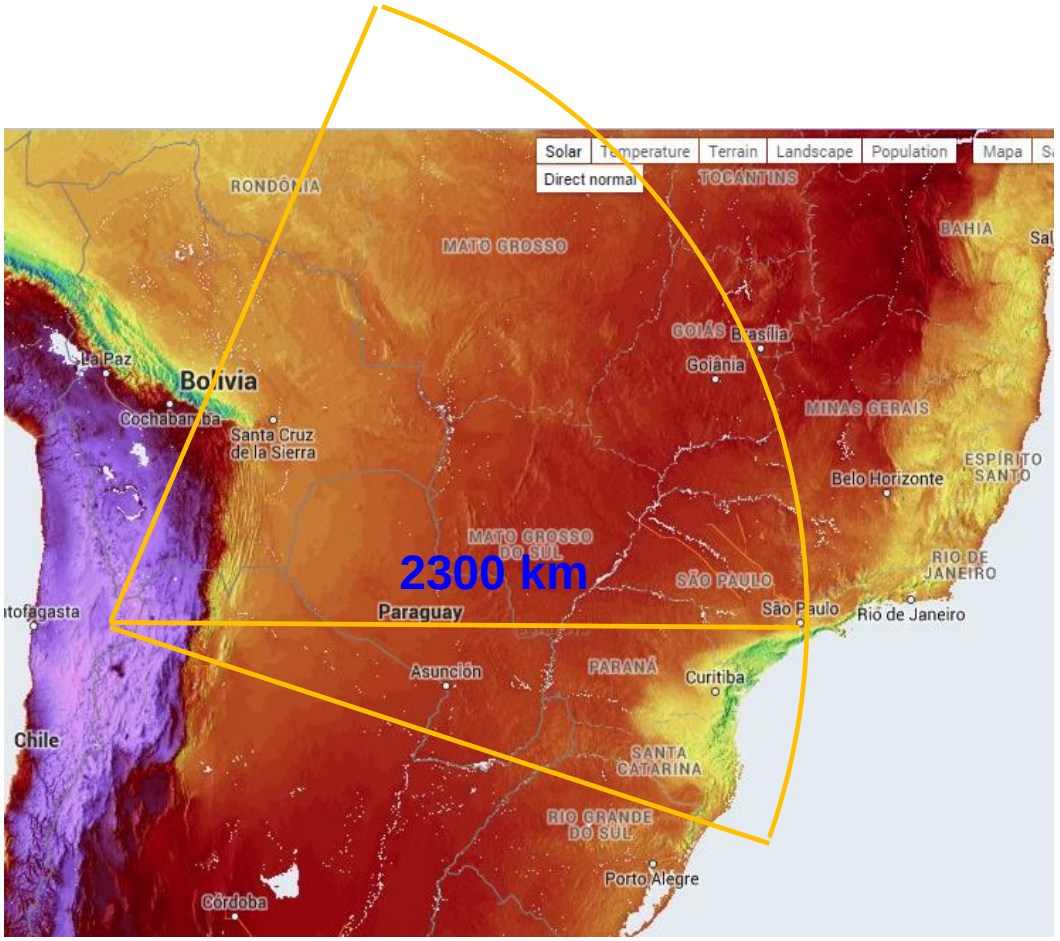
US$12 MILLION — CHILEAN GOVERNMENT

US$5 MILLION — PRIVATE SECTOR CONTRIBUTIONS

http://www.desertmodule.cl/

A Regional View

- A solar hub in northern Chile could supply energy to a large portion of central South America
- Range of 2300 km, to Sao Paulo region (South of Brazil, Peru, Bolivia, North of Argentina, Uruguay, Paraguay)
- 2300 km of transmission lines is not difficult, many examples worldwide
- **Larger hydro uncertainty due to climate change – solar+hydro could be the solution (Brazil: 64% Hydro)**



Source: Internal Analysis – Fraunhofer Chile Research – Solargis

SOLAR ENERGY
An Opportunity for Chile

- The global energy transformation is **the challenge of our generation**, as a first step of the needed transformation to sustainability.
- A **near-100% renewable energy system is possible**, at similar cost as today's energy supply.
- Big challenges, big opportunities: Long term view
  - **Storage** (Pump storage, BESS, H_2, etc)
  - **Grid Integration** / Solar (North) + Hydro (South) / **Latinamerican Grid**
  - **Transmission** capacity needed – Critical issue!
  - **Operational Issues**: Forecasting, Soiling, Adaptation to Local Conditions
  - Solar + **Large Desalination Centers** : Solar Energy → Water!
- Chile can take a leading role in the field of R&D for „**high radiation solar**" technologies.
- Chile can develop a **strong solar industry** (new jobs – new industries) to supply power with high level of security of supply and at competitive prices.

FRAUNHOFER CHILE:
A POLE OF INNOVATION FOR LATIN AMERICA

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Fraunhofer Chile Research – Center for Solar Energy Technology | FCR-CSET
SOLAR Energy in Chile

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