



# Business models in a hydrothermal power system: coping with restrictions and uncertainty

Hugh Rudnick

Boston, July 2016


# Summary

The Chilean power market is described with a cost based structure within a mandatory pool restricted to generators that can also subscribe wholesale PPA contracts.

Generators may withdraw their own or else's electricity from the system to serve their contracts. The energy they inject to the market at the instantaneous marginal cost of the injection node and they pay the withdrawn energy at the cost of the withdrawal node. Prices at those nodes may differ considerably depending on hydrological conditions and transmission restrictions.

Generation companies have to consider these factors when deciding their contracting levels, varying their approach if they are thermoelectric based generators or hydroelectric ones, and depending on their geographic location. Contracting becomes more challenging for highly intermittent renewables, operating in a 24/7 contract scheme.

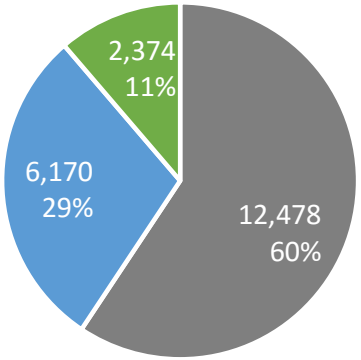
A discussion is made of the ways different technologies cope with restrictions and uncertainty.

# Index

- Description of Chilean power market
- Spot market and PPAs analysis
- Contracting level analysis
- Contracting opportunities in Chile
- Conclusions


# Chile facts

| | |
|---|---|
| Population (2014) | 17 ,762, 964 |
| GDP (PPP) per capita (2014) | $14,980 |




- Thermal
- Renewable
- Non-conventional renewable

SIC+SING installed capacity (June 2016)

21,022 MW

| | |
|---|---|
| Max power demand SIC (2015) | 7,557 MW |
| Max power demand SING (2015) | 2,290 MW |
| Annual energy demand SIC + SING (2015) | 66,468 GWh |

- Electricity sector reform in 1982
- All companies privately owned

Source: World Bank, CDEC, Systep

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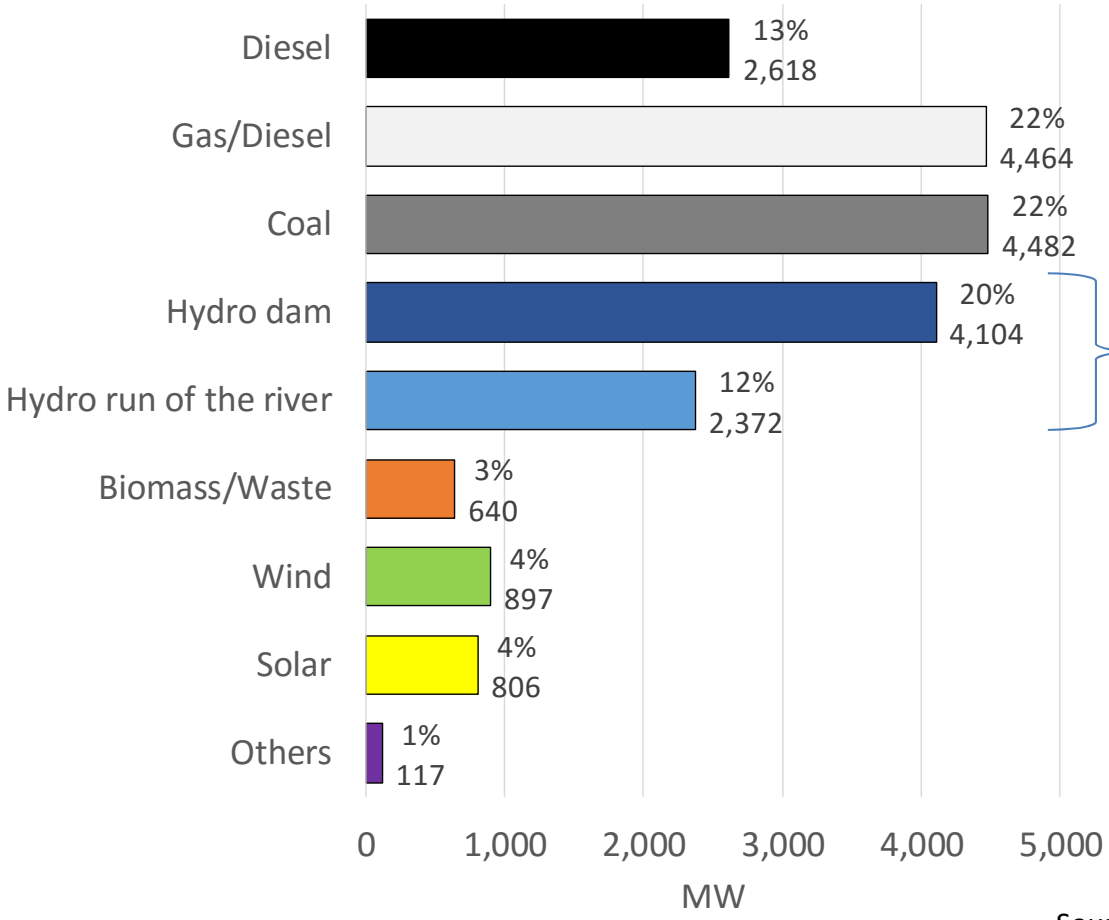
# Gross capacity by technology

- SIC + SING (April 2016)



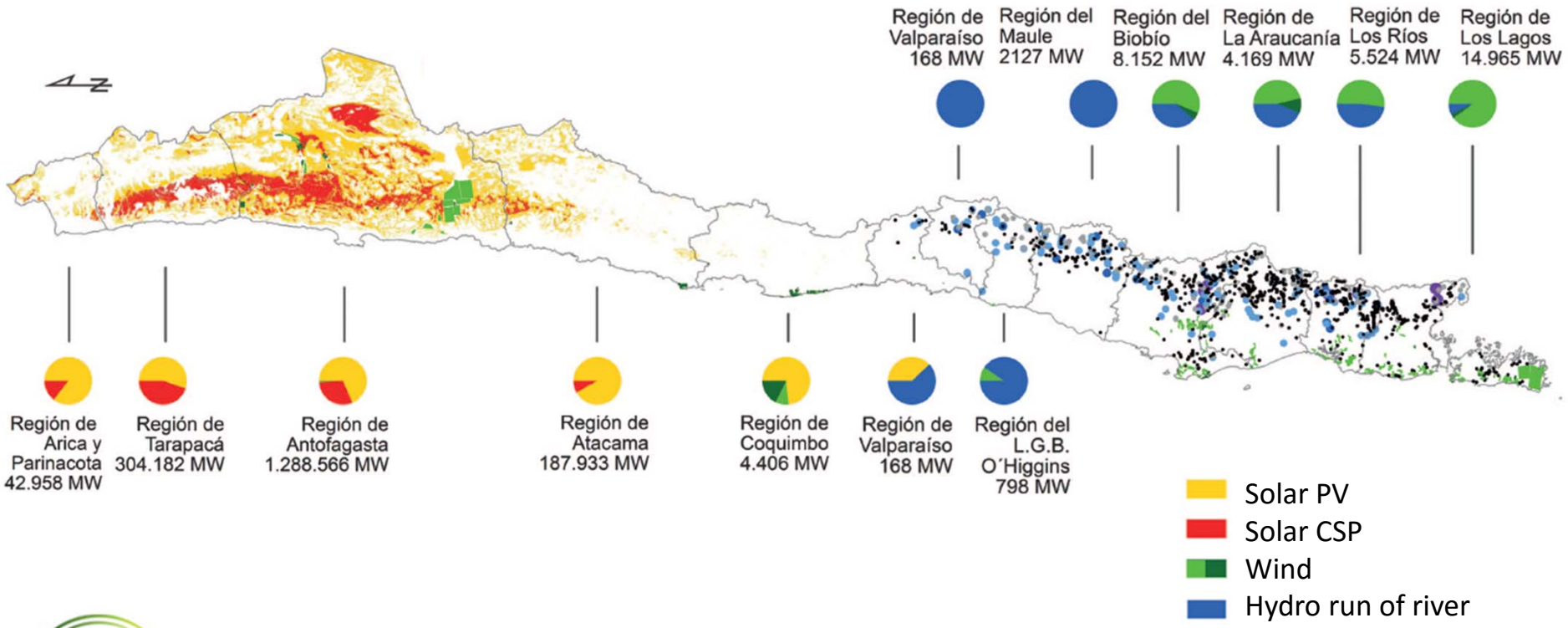

Hydro total: 6,476 MW

Total: 20,500 MW

Source: CDEC, Systep

# Large renewable energy potential

- Hydro, solar and wind potential of 1,865,000 MW
- Geothermal and biomass potential of 2,000 MW each




Source: Mesa ERNC Energía 2050, Ministry of Energy, Chile

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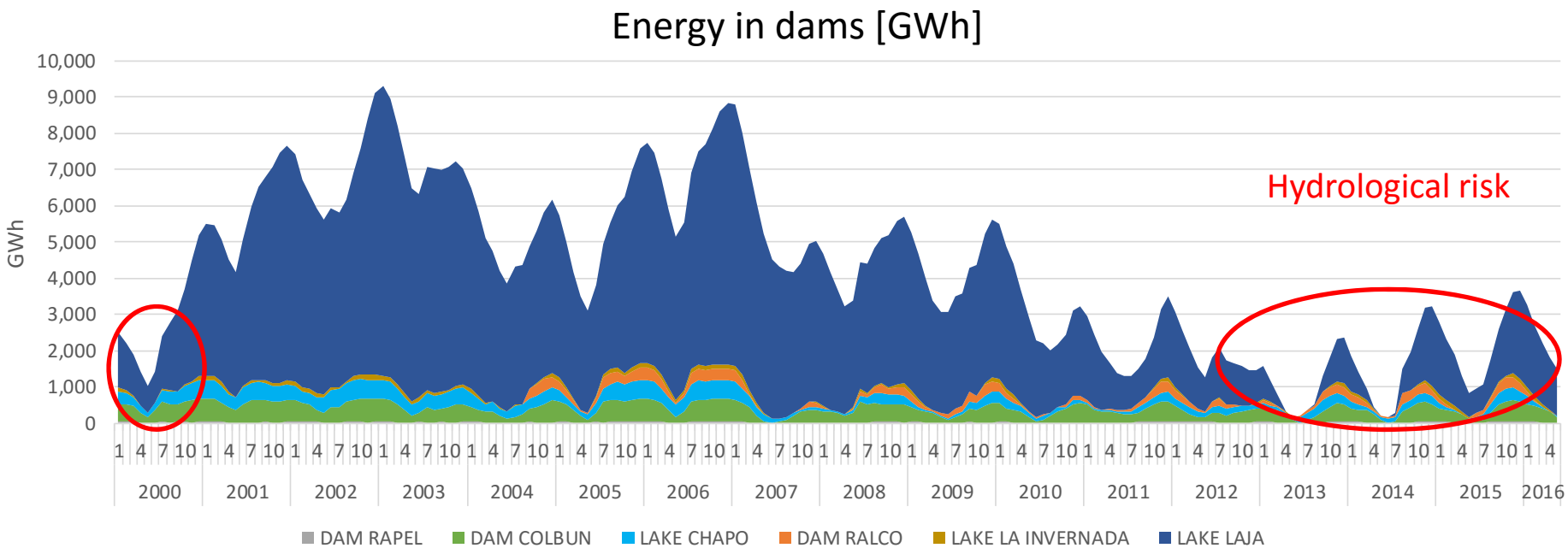
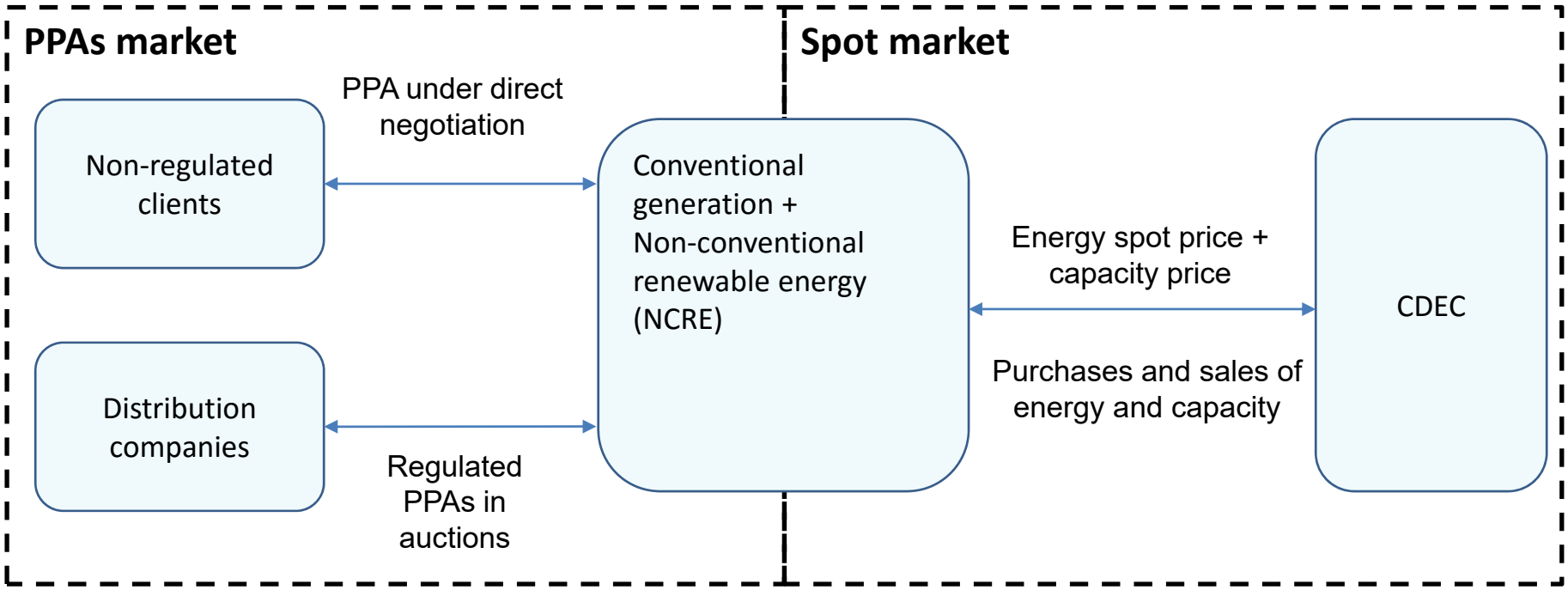
# Randomness due to hydro energy

- Hydrological variation is a large source of uncertainty in the Chilean power system




Source: CDEC-SIC, Systep

# Energy trading scheme




- System operator (CDEC) does not take account of PPAs for dispatch decisions
- PPAs are financial compromises, not production enforcements

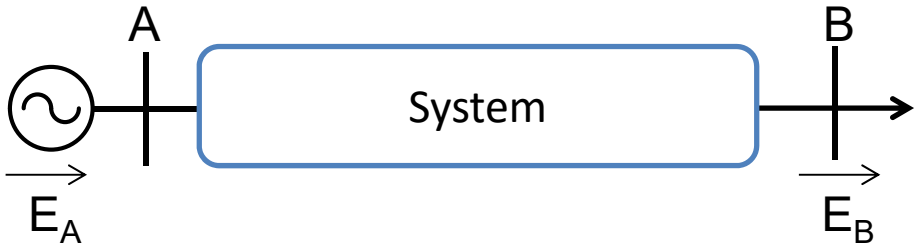
- Generators are dispatched by their variable costs
- Only generators have access to the spot market
- Demand must be 100% contracted

Source: Systep

# Energy trading scheme

- **Energy incomes and costs**

**Injection node A:**
$MgC_A$ : marginal cost
$E_A$: injected energy
VarC : variable cost




**Withdrawal node B:**
$MgC_B$ : Marginal cost
$P_{PPA}$ : PPA price
$E_B$ : withdrawn energy

- All generators sell all their production to the spot market at a price equal to the marginal cost of the system at the injection point

- If the generator has a PPA, the energy sold must be withdrawn from the spot market at the marginal cost at the withdrawal point, and the same amount of energy is sold to the consumer at the PPA price

- The following expression represents energy revenues

PPA energy margin

$$\text{Energy revenues} = \underbrace{\mathbf{MgC_A}\cdot\mathbf{E_A} - \mathbf{MgC_B}\cdot E_B}_{\text{Spot balance}} + \underbrace{P_{PPA}\cdot E_B}_{\text{PPA incomes}} - \text{VarC}\cdot\mathbf{E_A}$$

Source: Systep

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# Spot Market and PPAs – Randomness

- Energy revenues without PPA $\mathbf{MgC_A \cdot E_A} - \mathrm{VarC} \cdot \mathbf{E_A}$
  - High variance due to marginal costs unpredictability regarding hydrological scenarios, demand growth, generation and transmission expansion scenarios, fuel costs, intermittent renewable generation, among others
- Energy revenues with PPA

PPA energy margin

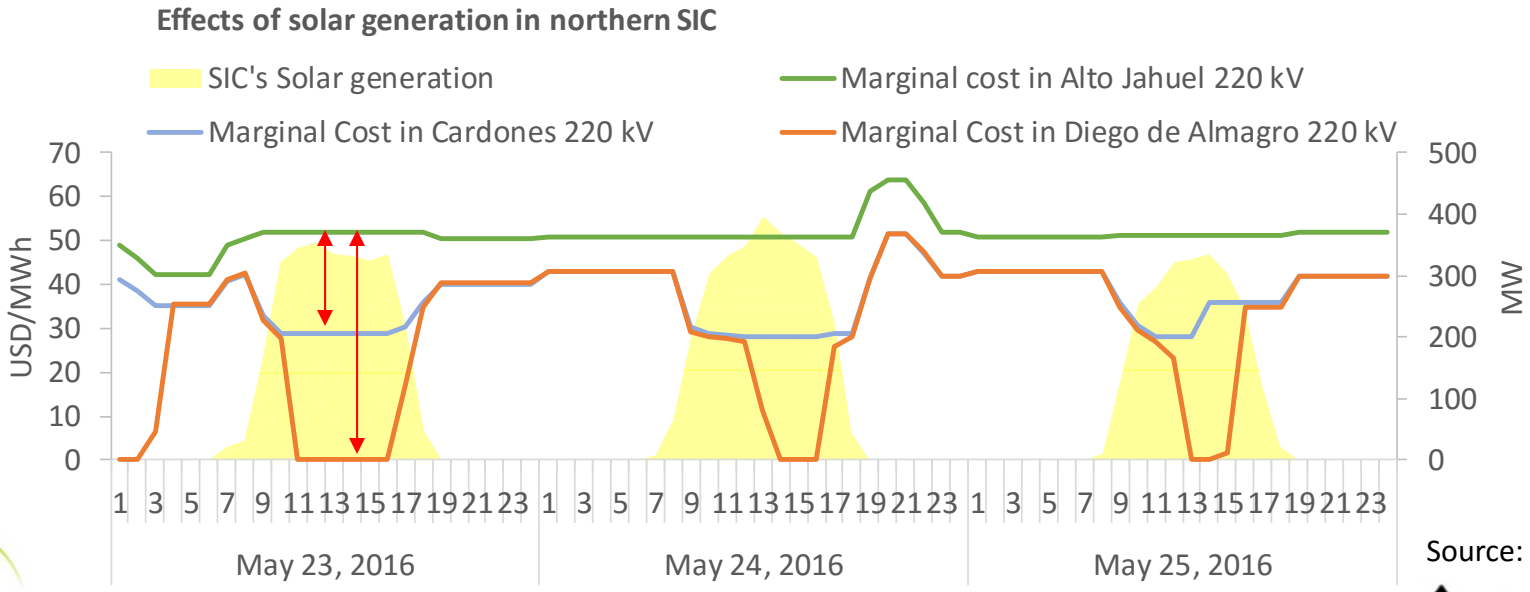
$$\underbrace{\mathbf{MgC_A \cdot E_A} - \mathbf{MgC_B} \cdot E_B}_{\text{Spot balance}} + \underbrace{P_{PPA} \cdot E_B}_{\text{PPA incomes}} - \mathrm{VarC} \cdot \mathbf{E_A}$$

  - Stable energy revenues are accomplished when:
  - $\mathbf{MgC_A} \approx \mathbf{MgC_B}$
  - $\mathbf{E_A}$ covers $E_B$ in each time period

Random variables
$\mathbf{MgC_A}$ $\mathbf{MgC_B}$ $\mathbf{E_A}$

# Spot Market and PPAs – Decoupling risk

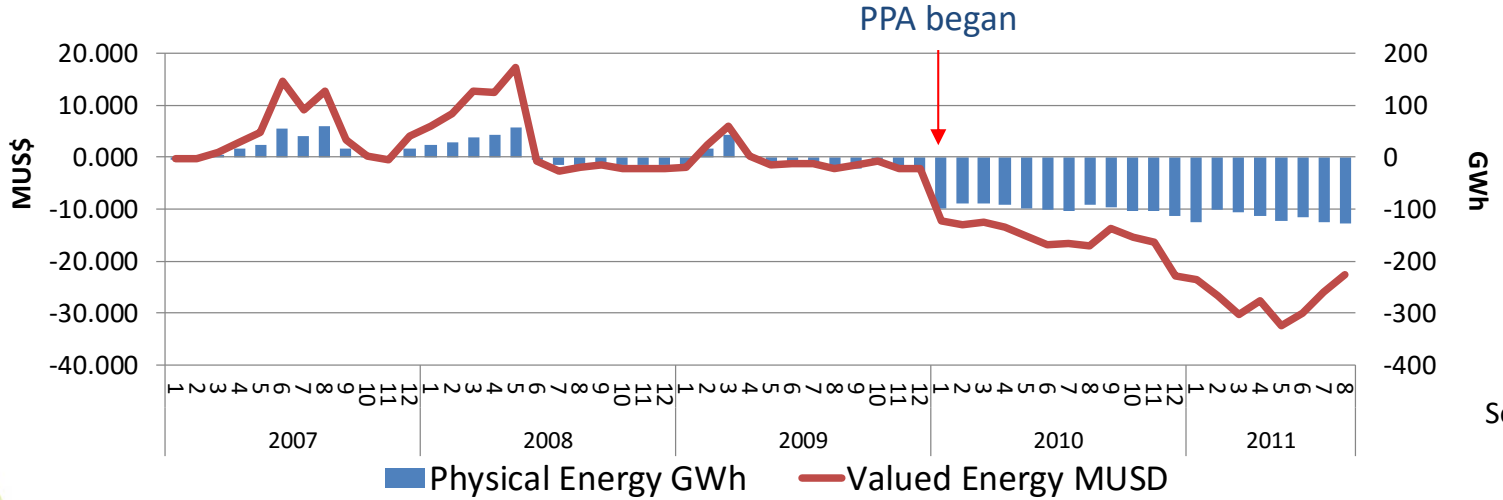
- **Differences in injection and withdrawal marginal costs ($MgC_A \neq MgC_B$)**
  - Transmission congestions produce price decoupling
  - Currently, transmission lines connecting the central and northern SIC present severe bottlenecks
  - The 500 kV transmission system intended to overcome this situation is expected to be commissioned in January 2018




Source: CDEC, Systep

# Spot Market and PPAs – Production risk

- **Differences in generated energy and withdrawn energy ($E_A$ does not cover $E_B$)**
  - Example: Campanario was a generation company that began its operation in 2007 with diesel generation units
  - It signed a PPA with distribution companies whose supply began in 2010
  - During 2010 and 2011, marginal costs were higher than the PPA price and its units were not operating due to their high variable costs
  - In late 2011 the company went out of business because PPA incomes could not cover the negative spot balance produced by injection and withdrawal unbalance




Source: CDEC, Systep

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# Contracting level analysis

Energy revenues $\tilde{\pi} = \boldsymbol{MgC_A} \cdot \boldsymbol{E_A} - \boldsymbol{MgC_B} \cdot E_B + P_{PPA} \cdot E_B - VarC \cdot \boldsymbol{E_A}$

- Investors aim to maximize their profit while accepting certain level of risk

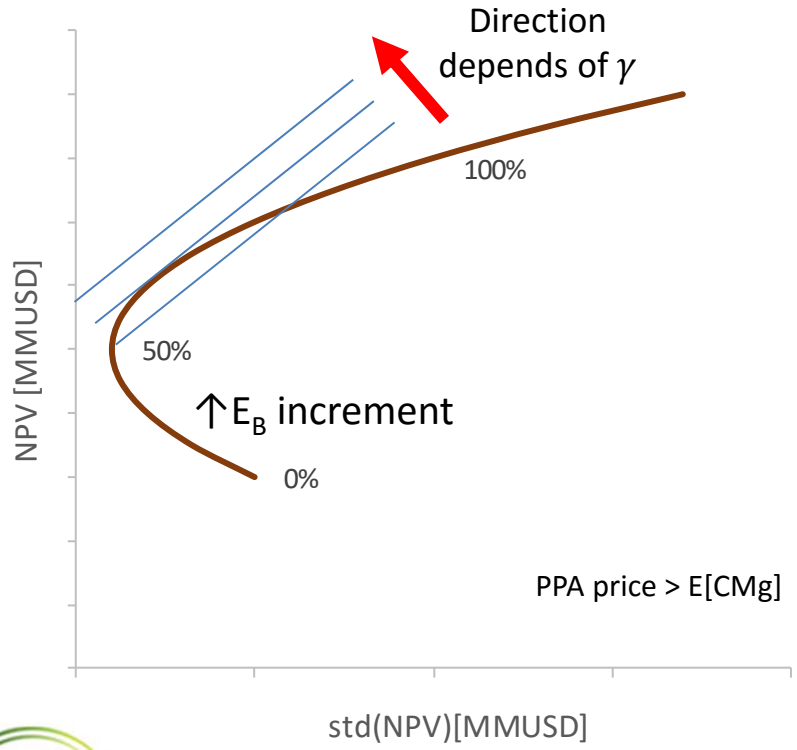
$$\max_{\tilde{\pi}} U(\tilde{\pi}) = \max_{E_B, P_{PPA}} (\gamma \cdot E[\tilde{\pi}] + (\gamma - 1) \cdot Var[\tilde{\pi}])$$

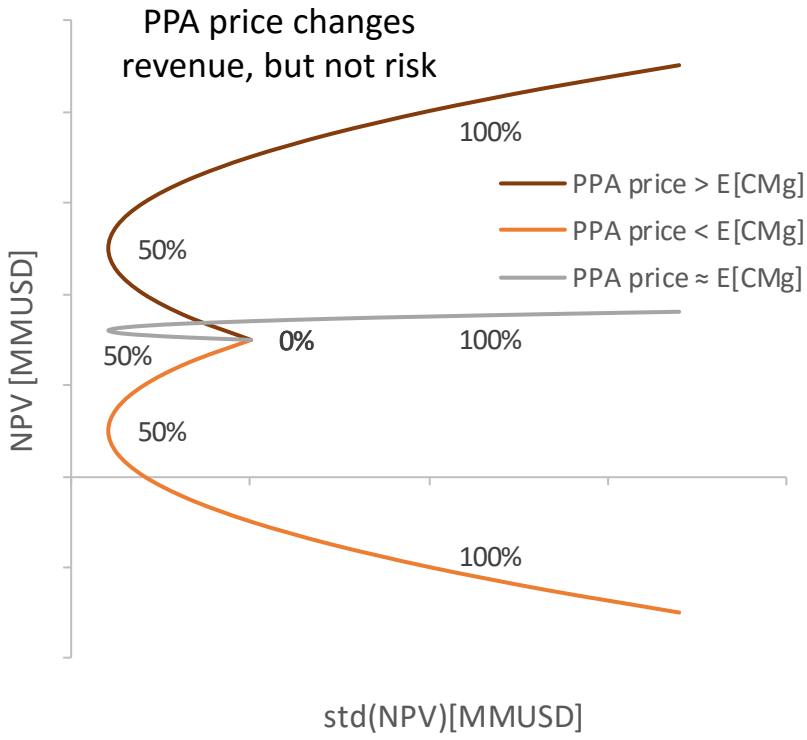
$\gamma$: Risk aversion coefficient ϵ [0,1]

- $Var[\tilde{\pi}]$ diminishes if an adequate energy level is contracted
- $E[\tilde{\pi}]$ may increase or decrease depending on the PPA price ($P_{PPA}$)

# Contracting level analysis

- Effects on risk revenue relation depend on the amount of contracted energy and PPA price $\max_{E_B, P_{PPA}} (\gamma \cdot E[\tilde{\pi}] + (\gamma - 1) \cdot Var[\tilde{\pi}])$



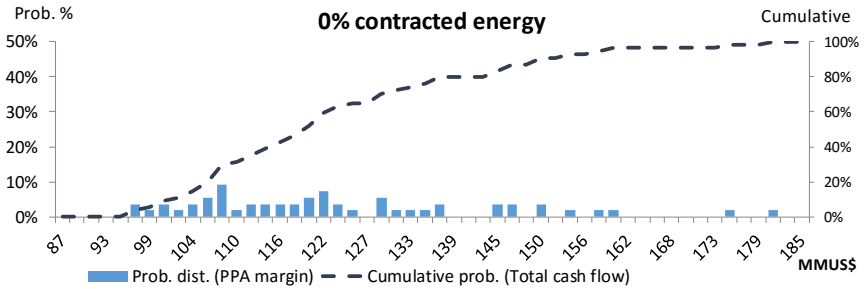



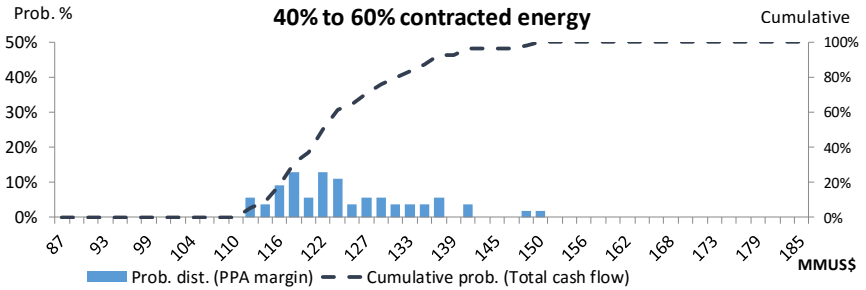

Source: Systep

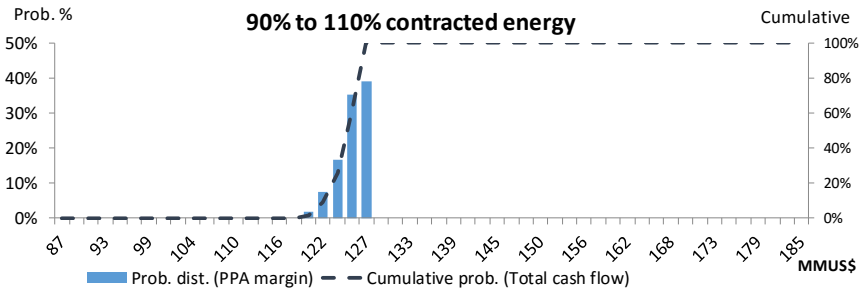
# Risk management – Thermal units

- Thermal units reduce their revenue risk when contracting nearly all of their energy production
- Distribution may vary depending on their capacity factor and operational costs

Revenue distribution with different energy contracting levels



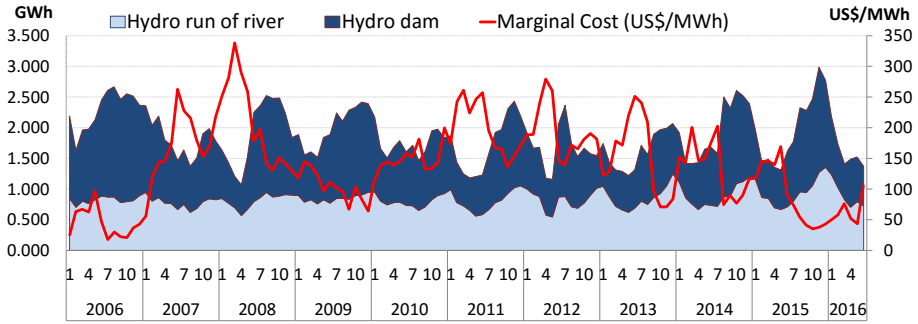




Source: Systep

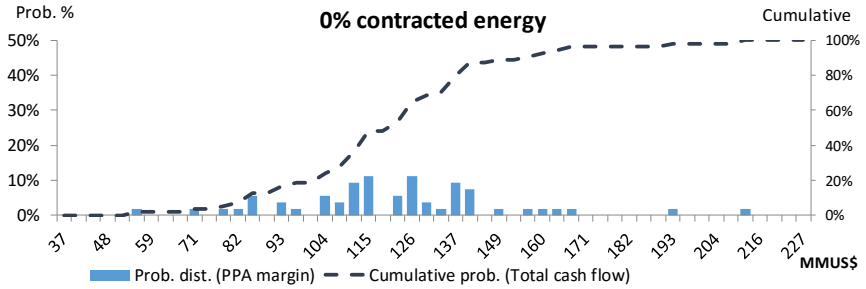
# Risk management – Hydro units

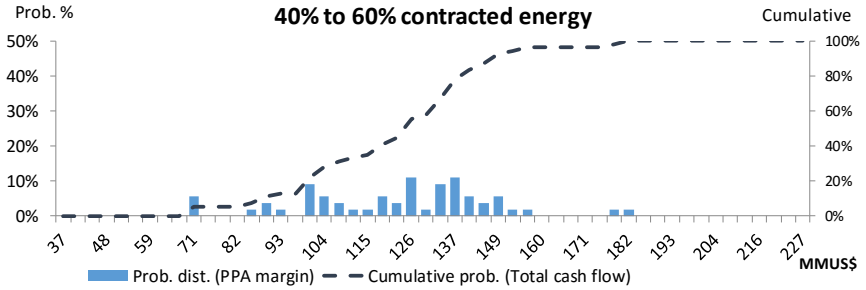
- Hydro units are highly exposed to hydrological risk
  - Hydro generators are more prone to buy energy at high prices when their generation is low, and to sell at low prices when their generation is high

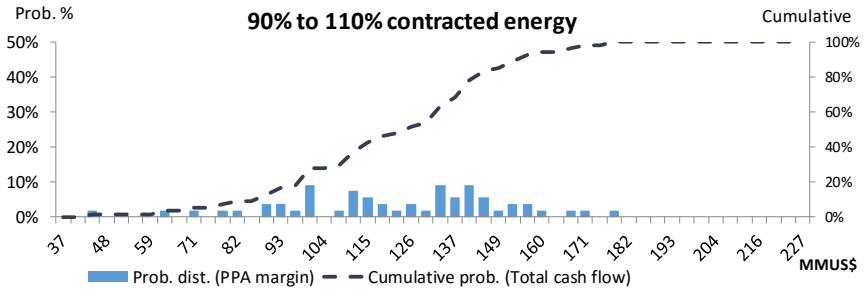



- To overcome this risk, hydro generators usually contract an amount of energy equivalent to their 90% exceedance probability

Revenue distribution with different energy contracting levels



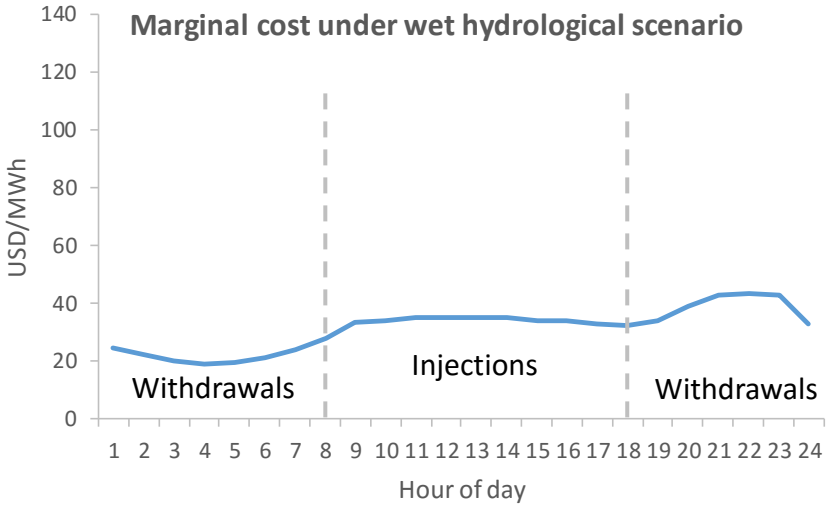



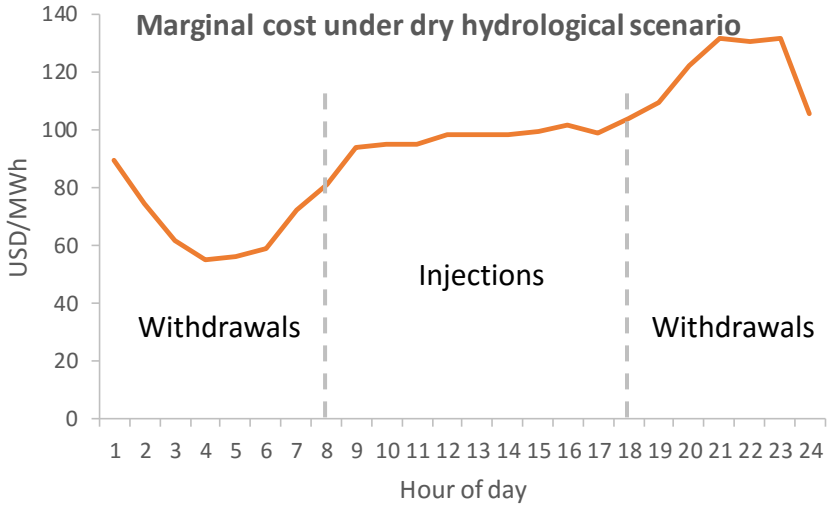




Source: Systep

# Risk management – Solar units

- Hydrological risks for a solar unit under a 24 hours PPA seem to be hedged, as long as energy withdrawals are similar to expected injections
  - Hydrological scenarios increase or diminish marginal costs of all hours of a day



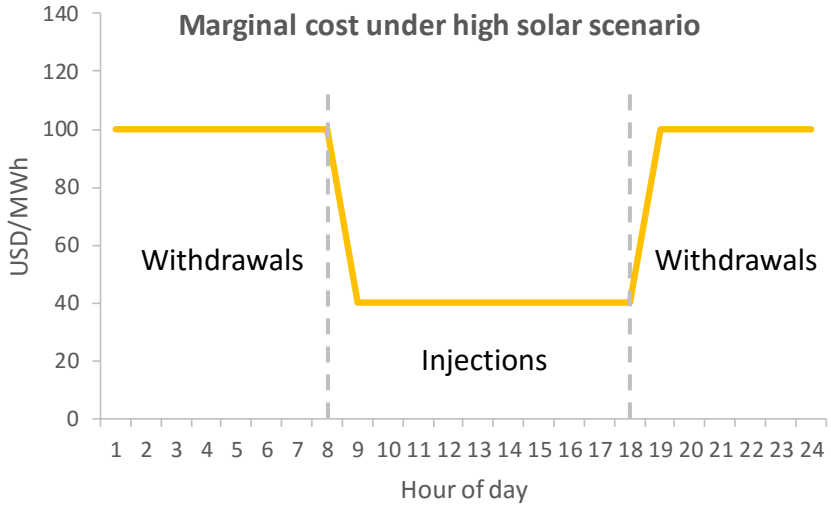




Injections cover withdrawals

Source: Systep

# Risk management – Solar units

- But other uncertainties, as a large deployment of solar generation or demand response schemes, could change the way daily hours usually correlate to each other, creating problems for a solar unit with a 24 hours PPA



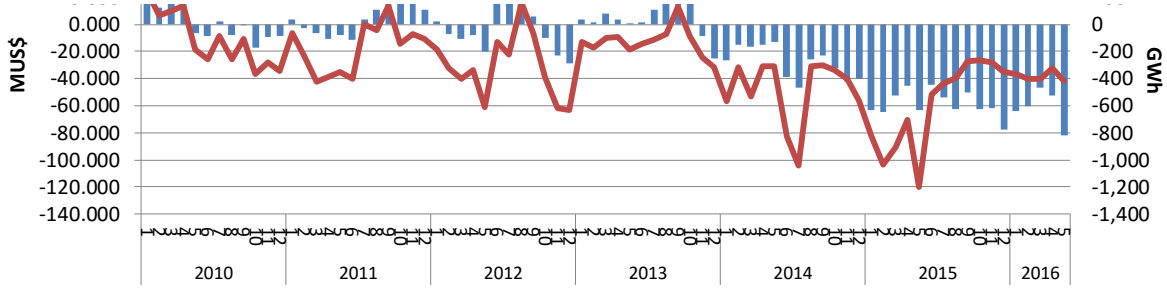

Injections do not cover withdrawals

Therefore, solar units should sign contracts with daylight hours supply

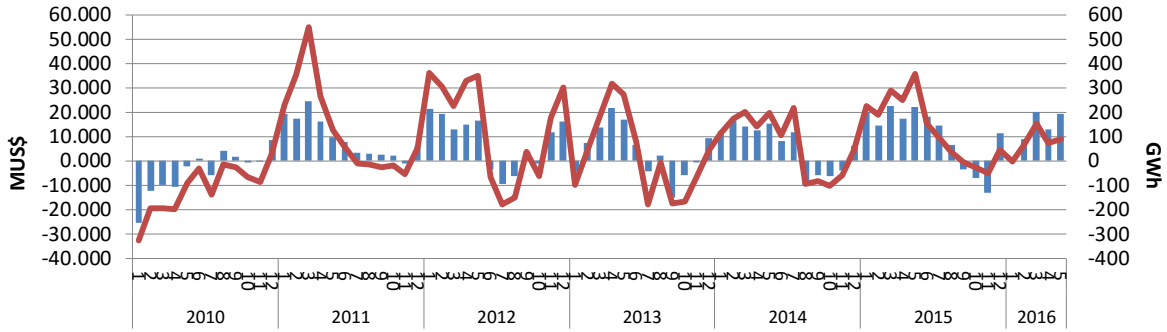
Source: Systep

# Historical contracting levels from large GenCos

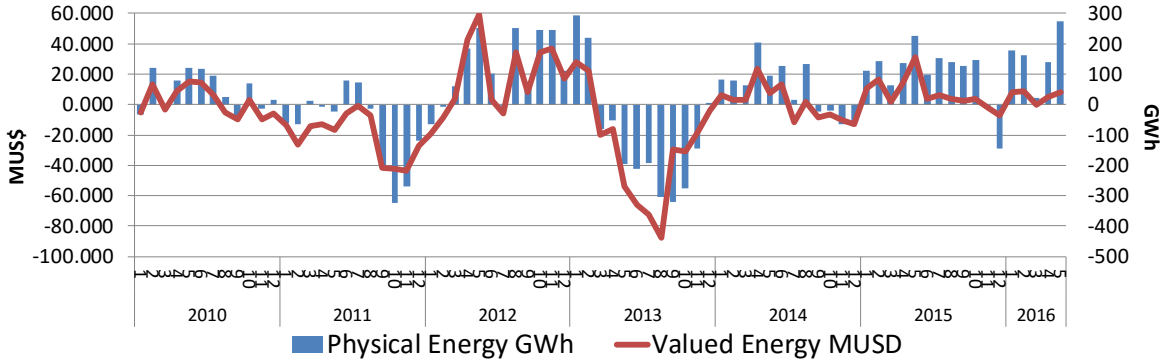
Endesa




Colbún




Gener




Source: CDEC, Systep

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# Low financing possibilities without PPAs

- Market participants expect lower and more unpredictable marginal costs in the future, therefore PPA are being required to obtain financing

"It is difficult nowadays for a renewable project to get financing without a PPA"

(…) Banks are not interested anymore in financing projects with PPAs indexed to market spot prices, only with long term PPAs (…)

ENERGÍA 26/10/2015

## Banco Bice: "Hoy es difícil que un proyecto de energía renovable se financie si no tiene contrato"

El volumen de negocios para la banca rondaría los US$ 1.400 millones al año, y hay alta competencia, dice el ejecutivo.

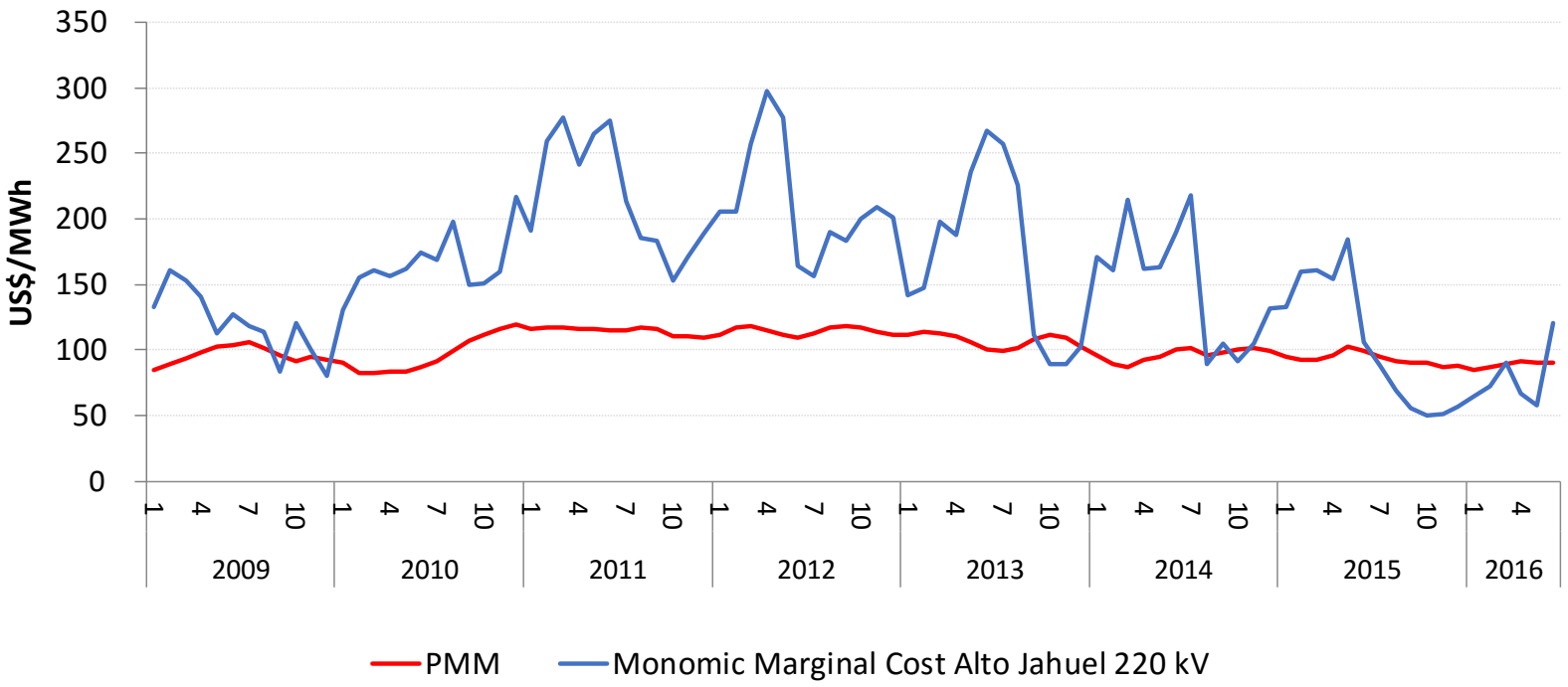
## Panorama financiero del sector energético

Publicado el *9 De Febrero Del 2016* Electricidad

Analistas del sector confiesan que la banca ya no está interesada en financiar contratos en el mercado spot, enfocándose en contratos de largo plazo, lo que plantea nuevos desafíos para los desarrolladores en generación, además de las menores proyecciones en el consumo, debido a la menor actividad de la minería.

# Historical monomic spot and PPA prices

- Energy prices have been higher than PPM (market average PPA price) for the past seven years



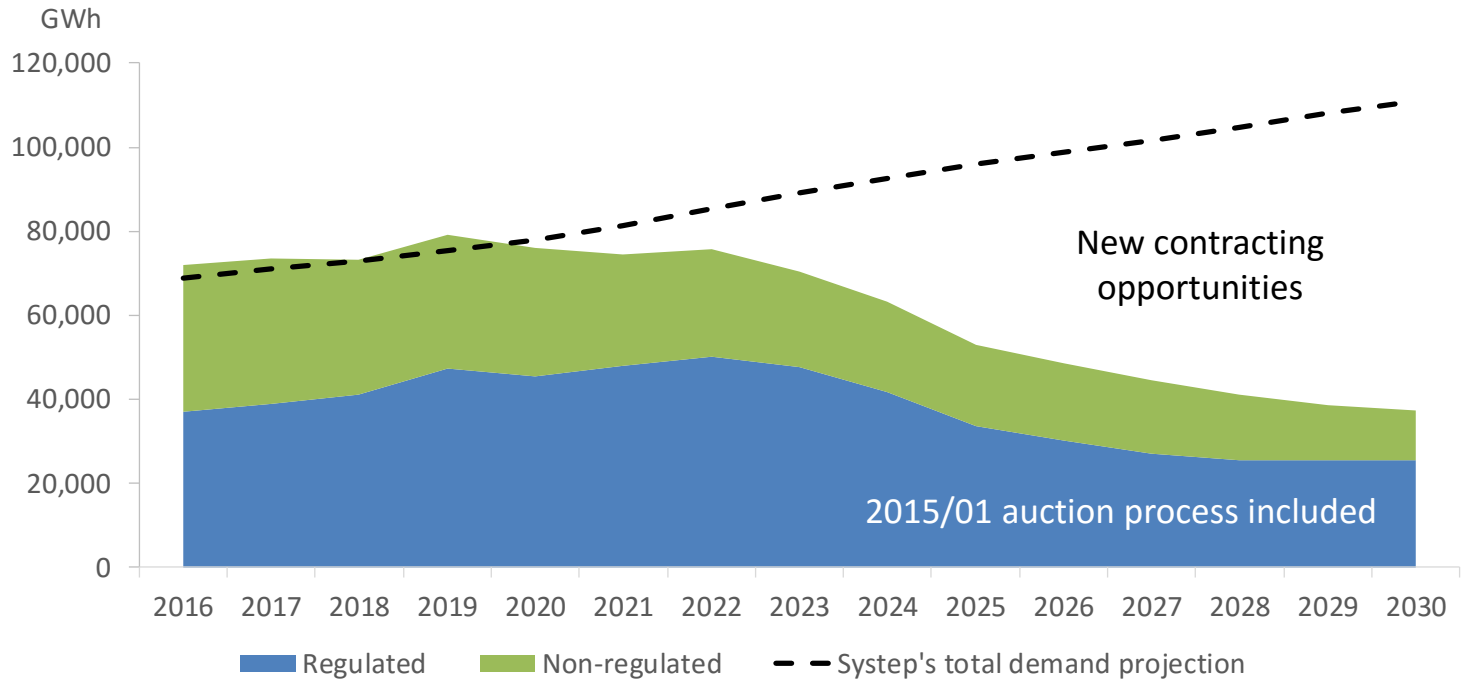

Source: CDEC, CNE, Systep

# PPA market – Non-regulated clients

- Contracting possibilities arise with new consumption projects (e.g. mining projects) or with the expiration of existing contracts
- PPA price is given by the long term vision of marginal costs that the generator and the consumer agree on
- These prices should have a downward trend due to a more competitive market

# PPA market – Total contracted energy

- Contracted energy from regulated and non-regulated clients in SIC and SING

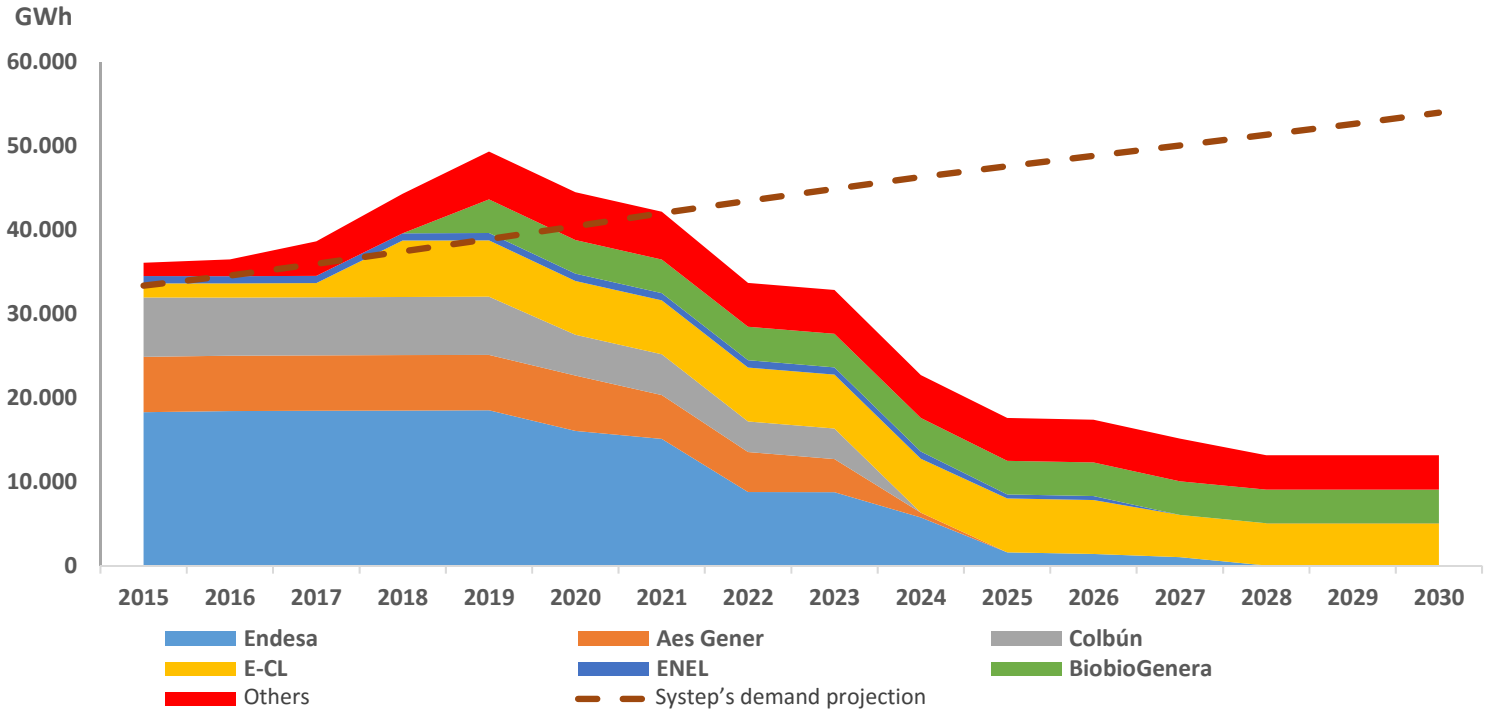



- New contracting opportunities would emerge from 2021 onwards

Source: CNE, Systep

# PPA market – Distribution auction process

- Contracted energy from regulated clients by generation company

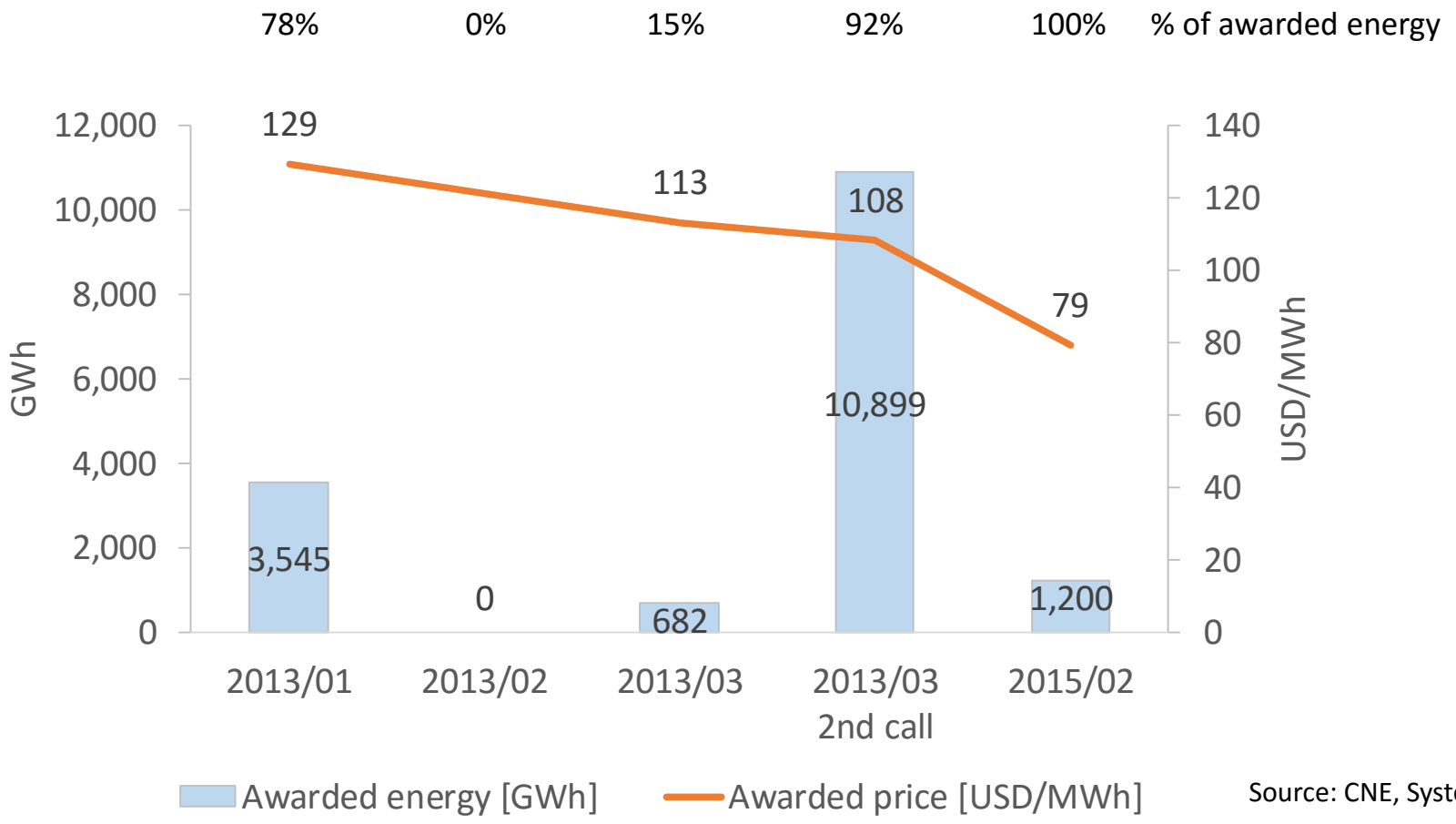



- High competition is expected in the 2015/01 auction process due to contract expirations from large generation companies

Source: CNE, Systep

# PPA market – Distribution auction process

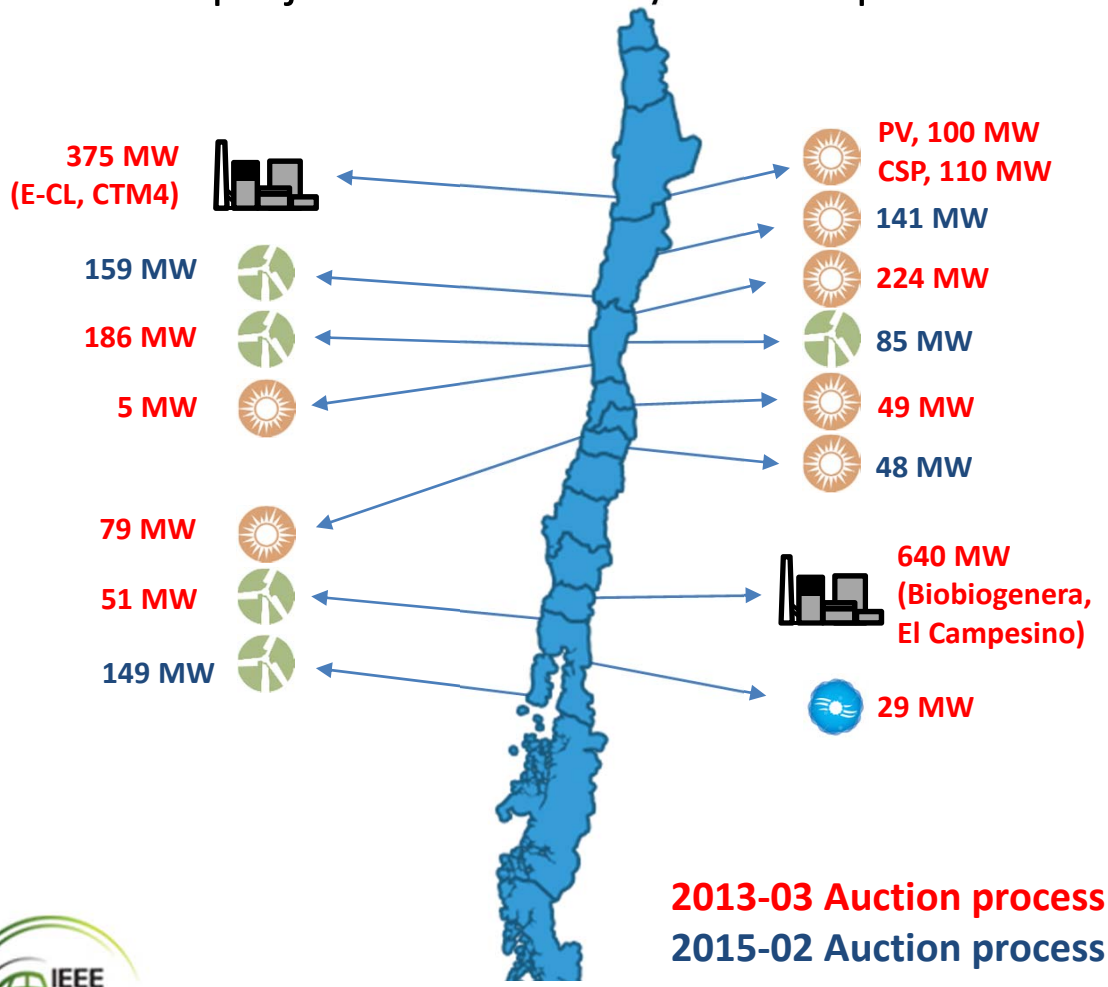
- Recent auction processes results




Source: CNE, Systep

# PPA market – Distribution auction process

- New projects sustained by auction process PPAs




**Summary**

| Technology | Total MW |
|---|---|
| LNG | 1,015 |
| Wind | 630 |
| Solar PV | 646 |
| Solar CSP | 110 |
| Hydro run of river | 29 |

Source: Systep

# Conclusions

- Long term PPAs help to reduce revenue variance in hydrothermal system when the correct amount of energy is contracted
- Large generation projects require PPAs to get financing, as banks demand hedge ratios that increase the possibilities of investment recovery
- While hydrological conditions are one of the largest sources of uncertainty in the Chilean power system, generation and transmission expansion scenarios and intermittent renewable generation are increasing their importance in the risk-return analysis



# Business models in a hydrothermal power system: coping with restrictions and uncertainty

Hugh Rudnick

Boston, July 2016