Challenges of power transmission expansion in a fast growing country

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Pontificia Universidad Católica de Chile

International Experience in Transmission Planning and Delivery
Imperial College, London, 11-12th January 2013
Abstract

The talk presents and discusses the power transmission expansion model of a fast growing country (Chile), where power capacity has to be doubled, approximately, every 10 years.

The market structure is explained, describing the wholesale spot market, contract PPA market, capacity market, locational marginal pricing, transmission toll scheme, and the centralized transmission expansion model.
Takeaways

Basis of Chilean model:
- Regulations that transmit economic signals to players, reflecting real costs and restrictions (including transmission ones), to achieve short and long term efficiency.
- Clear separation of wholesale roles (generation, transmission, operation), with no vertical integration (except distribution).

Fast growing countries need proactive transmission expansion models. An auction approach to build new predefined lines is proving an attractive efficient alternative in Chile.

Transmission system infrastructure development challenged by many uncertainties, mainly in power generation competitive investment decisions.

Need for evolving electricity market regulations, particularly in transmission. New challenge of operating multiple owner transmission systems.
Chilean Electricity Needs

- Energy growth around 6% per year
- High correlation between energy growth and GDP growth

**GDP (2000 US$)**
- PPP per cápita

**kWh per cápita**
## Chilean Electricity Market
### Interconnected Systems (December, 2011)

<table>
<thead>
<tr>
<th>Northern Interconnected System (SING)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max demand (MW)</td>
<td>2,002</td>
</tr>
<tr>
<td>Energy sales (GWh)</td>
<td>14,263</td>
</tr>
<tr>
<td>Installed Capacity (MW)</td>
<td>4,580</td>
</tr>
<tr>
<td>Region</td>
<td>I and II</td>
</tr>
<tr>
<td>Population</td>
<td>5.7%</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Central Interconnected System (SIC)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Max demand (MW)</td>
<td>6,158</td>
</tr>
<tr>
<td>Energy sales (GWh)</td>
<td>42,449</td>
</tr>
<tr>
<td>Installed Capacity (MW)</td>
<td>12,365</td>
</tr>
<tr>
<td>Region</td>
<td>III to X</td>
</tr>
<tr>
<td>Population</td>
<td>92.6%</td>
</tr>
</tbody>
</table>

- **Northern Interconnected System (SING)**
  - Max demand: 2,002 MW
  - Energy sales: 14,263 GWh
  - Installed Capacity: 4,580 MW
  - Region: I and II
  - Population: 5.7%

- **Central Interconnected System (SIC)**
  - Max demand: 6,158 MW
  - Energy sales: 42,449 GWh
  - Installed Capacity: 12,365 MW
  - Region: III to X
  - Population: 92.6%

- **Regions**
  - Aysen isolated networks
  - Magallanes isolated networks

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*Detailed data for each region can be found in the original source.*
Northern Interconnected System (SING)
Central Interconnected System (SIC)
Regulatory Principles

- Sufficiency & Efficiency in the Long Term
- Efficiency in the Short Term and avoid Market Power
- Adjustment between Contracts and Minimum Dispatch Cost

- Long Term Energy Contracts
- Compulsory Pool and Audited Costs
- Spot Transfers among Generators + Capacity Charge
Market Operation by ISO

Dispatch Example

Source: Systep, 2012

ISO completely independent of TO
Electricity Market and Products

Basic Concepts

• Generators supply (and sell) two main products:
  – Energy (supply energy hour by hour, MWh)
  – Capacity (supply peak demand, MW)
Generation fully contracted

- Contract Market
  - Demand buying through long term PPA contracts (15 to 20 years)
  - Investments based on contracts
  - New entrants can challenge incumbents via contracts

- Spot market as balance for differences market
- But cost based, eliminating market power by design

- Market competition takes place at PPA market, not in spot
Transmission
Open access passive market facilitator

Transmission companies separate from ISO
Transmission Regulation

Transmission:

- Longitudinal network
- Voltage over 23kV
- Regulated natural monopoly
- Remuneration independent of equipment loading and congestion
- Replacement value & auction value
- Rate of return over investment: 10% fixed by law
- Open access and public service
- Low risk activity
Trunk System: are the economically efficient and necessary facilities to supply overall system demand.*

Additional Systems: in-feed lines of generators and lines used exclusively by non-regulated customers.

Subtransmission System: are the facilities used by groups of customers (regulated or non-regulated price) located in distribution concession zones.

*defined by regulator every 4 years
Transmission tolls

- Providing system wide service
- Paid for that service

- Ex ante tolls determined by ISO, under regulated procedure
- Experts panel ruling on divergences

- Tolls reflecting:
  • Use of system under expected economic dispatch
  • Cost-benefit relation (more easily identified in long. system)
Transmission tolls

- Injections and withdrawals participation on power flow (magnitude & direction) are determined by Generalized Distribution Factors (GGDF / GLDF)*

Transmission tolls

\begin{align*}
\text{Toll } T_L &= \text{AVNR}_L + \text{COMA}_L - IT_L \\
T_L &= 0.8 \left( a_4^5 \cdot G_4^M + a_5^5 \cdot G_5^N + a_6^5 \cdot G_6^N \right) \\
&\quad + 0.2 \left( b_1^5 \cdot L_1^S + b_2^5 \cdot L_2^S + b_3^5 \cdot L_3^S \right)
\end{align*}

\begin{align*}
\text{Line 1} &\rightarrow T_1 \cdot a_1^L \cdot G_1^S \\
\text{Line 5} &\rightarrow T_5 \cdot \left[ 0.8 \left( a_4^5 \cdot G_4^M + a_5^5 \cdot G_5^N + a_6^5 \cdot G_6^N \right) \\
&\quad + 0.2 \left( b_1^5 \cdot L_1^S + b_2^5 \cdot L_2^S + b_3^5 \cdot L_3^S \right) \right]
\end{align*}

\begin{align*}
a_k^L &= f(GGDF^L) \\
b_j^L &= g(GLDF^L)
\end{align*}
Nodal prices
LMP
Short term locational spot prices reflecting:
• Generation costs
• Losses
• System congestion
Nodal prices

SIC real LMP decoupling along 2012
Congestion in trunk transmission
(2010-2012, % of hours a year)

Ref.: Gener, Chile
Nodal prices

Transmission expansion

SIC projected LMP decoupling
Impact of nodal prices

Injection G1 = 100
Injection G2 = 140
Injection G3 = 0
Withdraw G1 = 50
Withdraw G2 = 155
Withdraw G3 = 20

Losses = 15

Valuation of injections

<table>
<thead>
<tr>
<th></th>
<th>Price</th>
<th>Injection</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>G1</td>
<td>10,0</td>
<td>100,0</td>
<td>1000,0</td>
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<tr>
<td>G2</td>
<td>10,0</td>
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<tr>
<td>G3</td>
<td>11,4</td>
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</table>

\[\text{Value} = \text{Price} \times \text{Injection} \]

Valuation of withdrawals

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<th>Price</th>
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<td>11,4</td>
<td>50,0</td>
<td>571,4</td>
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<td>G2</td>
<td>11,4</td>
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<td>1771,4</td>
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<tr>
<td>G3</td>
<td>11,4</td>
<td>20,0</td>
<td>228,6</td>
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\[\text{Value} = \text{Price} \times \text{Withdraw} \]
**Balance**

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<tr>
<td>G1</td>
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<td>G2</td>
<td>15,0</td>
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<td>20,0</td>
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<tr>
<td>Total</td>
<td>15,0</td>
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<td>Marginal rev</td>
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### Transmission toll distribution

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<th>Flow</th>
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<td>G1</td>
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<td>G2</td>
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<td>G3</td>
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<tr>
<td>Total</td>
<td>240,0</td>
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### Transmission toll

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<td>Toll payment</td>
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<tr>
<td>G1 payment</td>
<td>136,9</td>
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<td>G2 payment</td>
<td>191,7</td>
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Valuation of injections

<table>
<thead>
<tr>
<th></th>
<th>Price</th>
<th>Injection</th>
<th>Value</th>
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</thead>
<tbody>
<tr>
<td>G1</td>
<td>10.0</td>
<td>100.0</td>
<td>1000.0</td>
</tr>
<tr>
<td>G2</td>
<td>10.0</td>
<td>140.0</td>
<td>1400.0</td>
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<td>G3</td>
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<td>240.0</td>
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Valuation of withdrawals

<table>
<thead>
<tr>
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<th>Value</th>
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<tr>
<td>G1</td>
<td>15.0</td>
<td>50.0</td>
<td>750.0</td>
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<td>G2</td>
<td>15.0</td>
<td>160.0</td>
<td>2400.0</td>
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<td>G3</td>
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<td></td>
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<td>235.0</td>
<td>3525.0</td>
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2010 SIC Balance of injections and withdrawals

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<tr>
<th>Empresa</th>
<th>Transferencias de Energía (1)</th>
<th>Otros Pagos</th>
<th>Devoluciones IT</th>
<th>Transferencias de Potencia</th>
<th>Total Valorizado</th>
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<tbody>
<tr>
<td></td>
<td>Físico kWh</td>
<td>Valorizado</td>
<td>Físico kWh</td>
<td>Valorizado</td>
<td>Físico kWh</td>
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<tr>
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<td>-110,497,288,717</td>
<td>-692,743,139</td>
<td>8,083,842,554</td>
<td>-14,684,757,606</td>
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<tr>
<td>COLBUN</td>
<td>544,982,471</td>
<td>12,974,645,316</td>
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<td>PEHUENCHE</td>
<td>747,407,883</td>
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<td>706,790,700</td>
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<td>GUACOLDA</td>
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<td>-963,352,541</td>
<td>1,755,932,025</td>
<td>-6,578,066,520</td>
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<td>ARAUCO</td>
<td>369,904,954</td>
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<td>36,485,887</td>
<td>796,065,135</td>
<td>3,151,729,911</td>
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<tr>
<td>ESSA</td>
<td>481,336,040</td>
<td>40,730,028,035</td>
<td>2,560,921,465</td>
<td>92,436,502</td>
<td>4,077,500,376</td>
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<tr>
<td>TRANSELEC</td>
<td>-416,676,121</td>
<td>38,672,990,026</td>
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<td>7,676,228,353</td>
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<tr>
<td>STS</td>
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<td>166,436,467</td>
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<td>-49,555</td>
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<td>IBENER</td>
<td>20,712,889</td>
<td>-456,960,402</td>
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<td>628,551,690</td>
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<tr>
<td>SGA</td>
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<td>CTNC</td>
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<td>74,698,340</td>
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<td>SC DEL MAPO</td>
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<td>TECNORED</td>
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<td>NUEVA ENERGIA</td>
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<td>ELEKTRAGEN</td>
<td>3,008,698</td>
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<td>1,122,349,068</td>
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<tr>
<td>GESAN</td>
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<td>16,434,546</td>
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<td>PACIFIC HYDRO</td>
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<td>-64,705,825</td>
<td>196,298,460</td>
<td>-1,874,973,530</td>
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</tbody>
</table>
ORIGINAL EXPANSION REGULATION
1982-2003

• Only generators pay for transmission, use of system approach
• Market oriented transmission toll regulation
  – Two party negotiations, no coherency checks for the global system
  – Different understanding of area of influence
  – High transaction costs and barriers of entry to new investors
  – Remuneration risks (over or under payments)
  – Opportunities for free-riders
• Market oriented transmission expansion
  – Expansion linked to generator investments or specific wholesale loads
  – Expansion needs originated by demand growth are not necessarily fulfilled
  – Questionable transmission solutions
  – Over and under investment
  – No simple solutions to congestion problems –reliability problems
Questionable expansion solutions

1996 system

Transelec expansion proposal

Colbun solution 1997

[Schematics showing electrical systems and transmission lines]
NEW TRANSMISSION EXPANSION

2004

• Cooperative scheme, with valuation and expansion of the trunk system determined every 4 years through a Trunk System Study (ETT) prepared by an external consultant.
• All agents participate in the study via a consultation process.
• The study determines the value of transmission installations.
• The study defines a preliminary 4 year expansion plan.
• All agents participate in the study via a consultation process (Regulator, SIC and SING gencos, SIC and SING trunk transcos, discos and large consumers).

• Study assigned to consultant through international tender.

• Study determines the trunk system VI (investment), COMA (operation), Economic Life and Indexation Formula (for existing installations).

• Study subject to Experts Panel process.
• Study determines a four year referential transmission expansion plan.

• Expansion depends on expected generation investments (generation expansion plan determined by regulator) and load forecasts.
Generation expansion plans (indicative)

Minimizing investment + operation + unserved energy under competitive environment

Need to consider uncertainties on hydro energy production in SIC
• The expansion plan is revised and adapted by the operator every year and the regulator defines the definitive plan. All agents participate in the revision.

• The trunk system expansion projects may be upgrades of the existing system or new projects:
  • Upgrades of the existing system are assigned directly to the facility owner (awarded through auction to the contractor with minimum value of investment VI, with a cap VI+15%)
  • New projects are awarded through a competitive auction process called by the operator (winner is the company that offers the minimum AVI+COMA, valid for 20 years)
Transmission system expansion
SIC 2012 auction process

<table>
<thead>
<tr>
<th>#</th>
<th>Project</th>
<th>$V_{ref}$ (MMUSD)</th>
<th>Length (km)</th>
<th>COMA (%)</th>
<th>Bidders</th>
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<tbody>
<tr>
<td>1</td>
<td>Subestación Seccionadora Lo Aguirre</td>
<td>69.02</td>
<td>-</td>
<td>1.44</td>
<td>5</td>
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<tr>
<td>2</td>
<td>Charrúa – Ancoa 2x500 kV (1C)</td>
<td>140.40</td>
<td>196.55</td>
<td>1.44</td>
<td>3</td>
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<tr>
<td>3</td>
<td>Pan de Azúcar – Polpaico 2x500 kV</td>
<td>280.00</td>
<td>401.80</td>
<td>1.5</td>
<td>5</td>
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<tr>
<td>4</td>
<td>Maintencillo-Pan de Azúcar 2x500 kV</td>
<td>130.11</td>
<td>209.20</td>
<td>1.58</td>
<td>5</td>
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<tr>
<td>5</td>
<td>Cardones – Maintencillo 2x500 kV</td>
<td>79.32</td>
<td>132.40</td>
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<td>5</td>
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<tr>
<td>6</td>
<td>Cardones – Diego Almagro 2x220 kV (1C)</td>
<td>37.00</td>
<td>152.00</td>
<td>2.07</td>
<td>5</td>
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<tr>
<td>7</td>
<td>Ciruelos – Pichirropulli 2x220 kV (1C)</td>
<td>45.49</td>
<td>83.00</td>
<td>2.07</td>
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<td>8</td>
<td>CER 100/-60 MVaR S/E Cardones</td>
<td>20.70</td>
<td>-</td>
<td>2.07</td>
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</tbody>
</table>

Bidders: 2 Colombian, 2 Spanish, 1 Brazilian, 1 Israeli and 2 Chilean companies
Transmission system expansion

SIC auction process - bids for main lines

Before ETT 2006

Years 2007-2010

Years 2011-2014
Construction of new installations

- Each transmission expansion is auctioned by a “closed envelope” scheme, where each bidder offers a fixed annual remuneration for its construction and operation.
  - Successful auctions (except for minimum administrative problems).
  - Lack of information provided not perceived as a limitation by newcomers.
  - The auction winner (smallest bid) starts to receive the requested remuneration when the facility starts operation. The annual rent is fixed during the first 20 years (indexed), and after that period goes into the four year valuation ETT process.
  - No congestion revenues are assigned to the transmission lines.
  - Building timing restrictions and penalties imposed by delays in complying.
  - Transmission facilities must comply with Grid Code and there are penalties imposed by Superintendence in case of disruptions.
  - New players must incorporate into a Transmission Company (Transco).
  - The ISO manages transmission operation, use of transmission and toll calculations, overlooking the network and each Transco. ISO’s duty is to secure supply and minimize cost of system operation.
### Timing restrictions

#### Trunk Expansion

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<th>2013</th>
<th>2014</th>
<th>2015</th>
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<td>OND</td>
<td>EFM</td>
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<td>Transmission lines</td>
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<td>Substations works (larger)</td>
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<tr>
<td>Substations works (minor)</td>
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</tbody>
</table>

#### Source: JC Araneda, Transelec

Dynamic market plus long environmental approval process and RoW negotiations require faster transmission expansion decisions for generation projects to develop.
Uncertainties and opportunity

Figures in Million USD

TransChile: 132
ISA: 489
ELECNOR: 140
TRANSELEC: 90
SAESA-Chilquinta: 83

Source: JC Araneda, Transelec
Uncertainties and opportunity in ETT

2006: One generation expansion scenario and deterministic analysis (10 years)

2010: Three generation scenarios and min max regret approach (15 years)

Investment value [MMUSD]

<table>
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<tr>
<th>ETT Study</th>
<th>Lines</th>
<th>Substations</th>
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<td>2006</td>
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<td>2010</td>
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<td>89,7</td>
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Load uncertainties

Timing of new mining projects in northern SIC

- **PASCUALAMA**
- **EL MORRO**
- **CASERONES**

MW

<table>
<thead>
<tr>
<th>Year</th>
<th>Systep (consultant)</th>
<th>Regulator</th>
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<tr>
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<td>2017</td>
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<tr>
<td>2018</td>
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</tbody>
</table>
How much use of *smart* options?

**Basic system operation**
- Reserves
- EDAG (intertripping)
- EDAC (load shedding)
- Maximum allowed flow

**Operation with smart control**
- Reserves
- EDAG
- EDAC
- Maximum allowed flow

System n-1 security may be incremented through smart control schemes.

Diverge positions at ISO, based on cost impacts.
Some difficulties and challenges

- Dissociation between competitive generation market and centralized transmission planning (Experts panel solving controversies)
  - Conflicitive interests of generation companies may lead to incremental solutions.
  - Transmitter interested in increasing investments –gold plating (n-1 discussion on transformers).

- Dynamic market plus long environmental approval process and RoW negotiations require faster transmission expansion decisions for generation projects to develop (Risks for incumbent and new investors)

- Uncertainty in value of investment for upgrades- cap too low in some cases, with no contractor offers, delaying commissioning.

- Risks of generation expansion and load forecast inaccuracy impact generators and load. Transmission protected from risks.
New challenges

SIC-SING interconnection (central vs merchant)

Anticipatory investments for new generation poles (20 years view)
Transmission expansion in Argentina*

• Mistrust of regulation
  • Decided that Transco and Regulator should not be responsible for transmission expansions

• Public Contest method
  • Users to propose, vote and pay for major expansions
  • Construction O&M out to competitive tender

*”Beyond regulation”, Stephen Littlechild, ESNIE Cargese, Corsica, 16 May 2006
Several years delay to much needed Fourth Line from Comahue (major generation source) to Buenos Aires (major demand center)

Congestion increasing on corridor
- Sept 1994 - 3 generators proposed 4th Line
- Public hearing Feb 1995 - 50% vote against (surprise and concern)
- May 1996 revised proposal – accepted
- Finally, 4th Line was not economic
  - Delay was socially beneficial, not costly
  - Cheaper to locate generation near demand instead
  - None of alleged problems materialized here
  - Public contest method worked well in other cases
Public contest method worked well

- Public Contest method made better use of existing lines
- Competitive tendering lowered costs and innovative technologies introduced
- Bidding to construct was very successful, new companies
- 4th Line: 4 bidders, cost/km about halved (pre-reform at least $230k/km, with 4th Line $130k/km)

- Regulation would have yielded to political pressures to build many uneconomic lines
- Method resisted political pressure and led to more economic outcomes than regulation
Transmission expansion in Brazil

Legend:
- Information flow
- Monetary flow
- Mechanisms of particular importance for uncertainty treatment/risk allocation

Source: L. Barroso, PSR, Brazil
Dealing with uncertainty in generation expansion:

- Generation expansion in Brazil made mainly via auctions, held 5 or 3 years before commissioning date of winner plants.
- 3 to 5 years for planning, auctioning and constructing transmission.
  - Environmental licensing is often cause for delays.
Challenges of power transmission expansion in a fast growing country

Hugh Rudnick
Professor
Pontificia Universidad Católica de Chile

International Experience in Transmission Planning and Delivery
Imperial College, London, 11-12th January 2013