



Challenges of power transmission expansion in a fast growing country

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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.

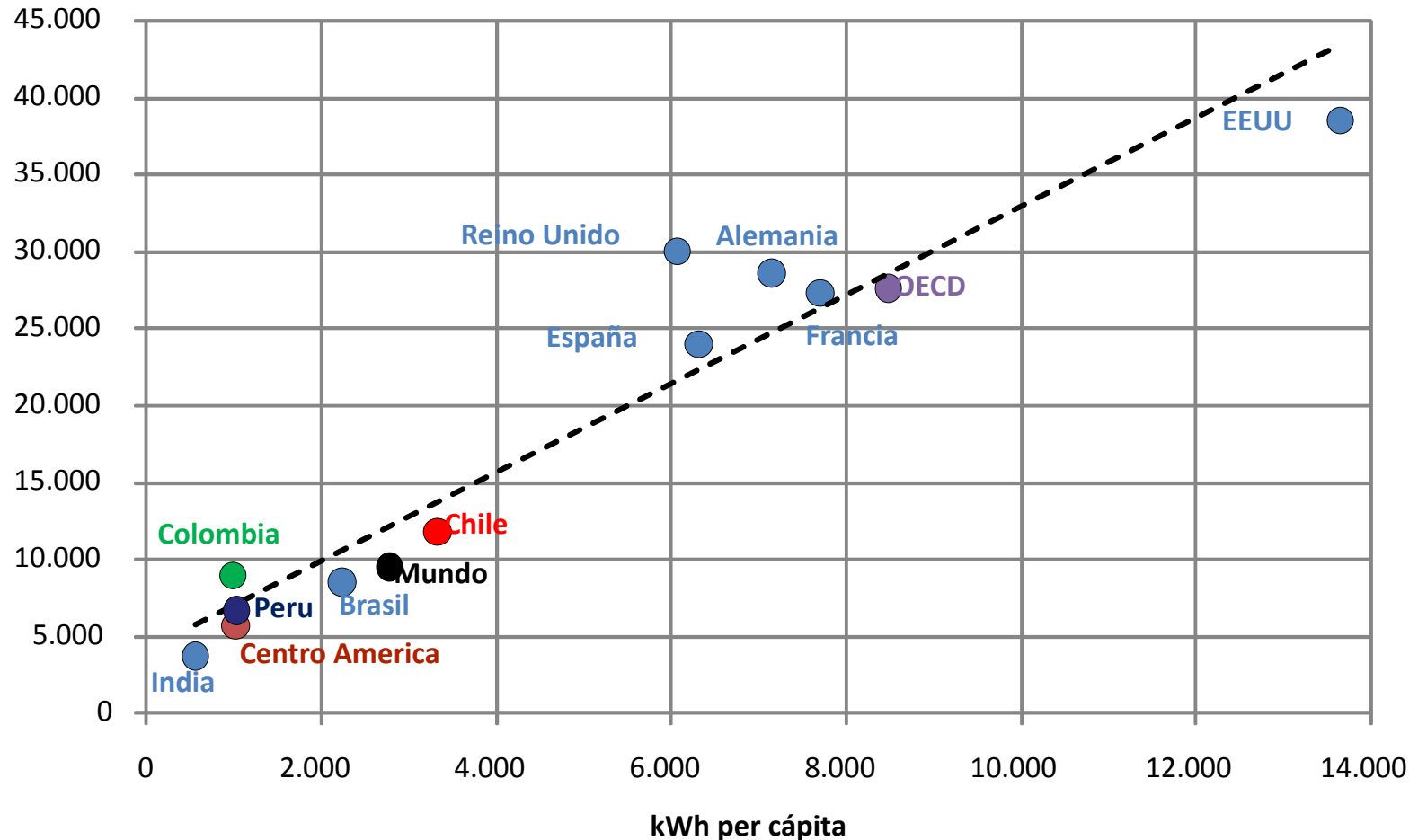
Transmission system infrastructure development challenged by many uncertainties, mainly in power generation competitive investment decisions.

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



Chilean Electricity Market

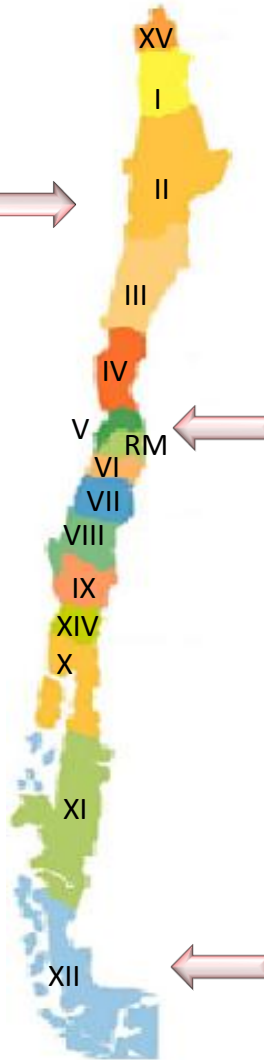
Interconnected Systems (December, 2011)

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

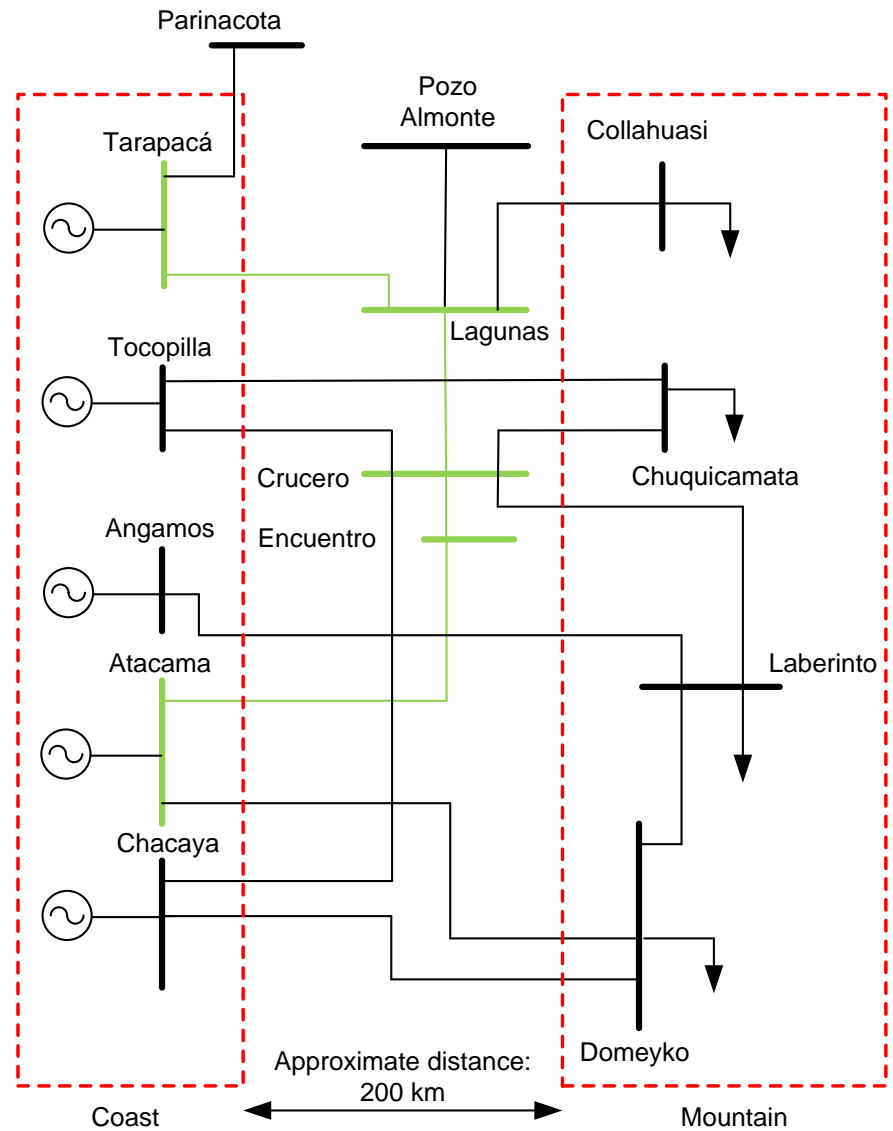
Central Interconnected System (SIC)	
Max demand (MW)	6,158
Energy sales (GWh)	42,449
Installed Capacity (MW)	12,365
Region	III to X
Population	92.6%

Aysen isolated networks

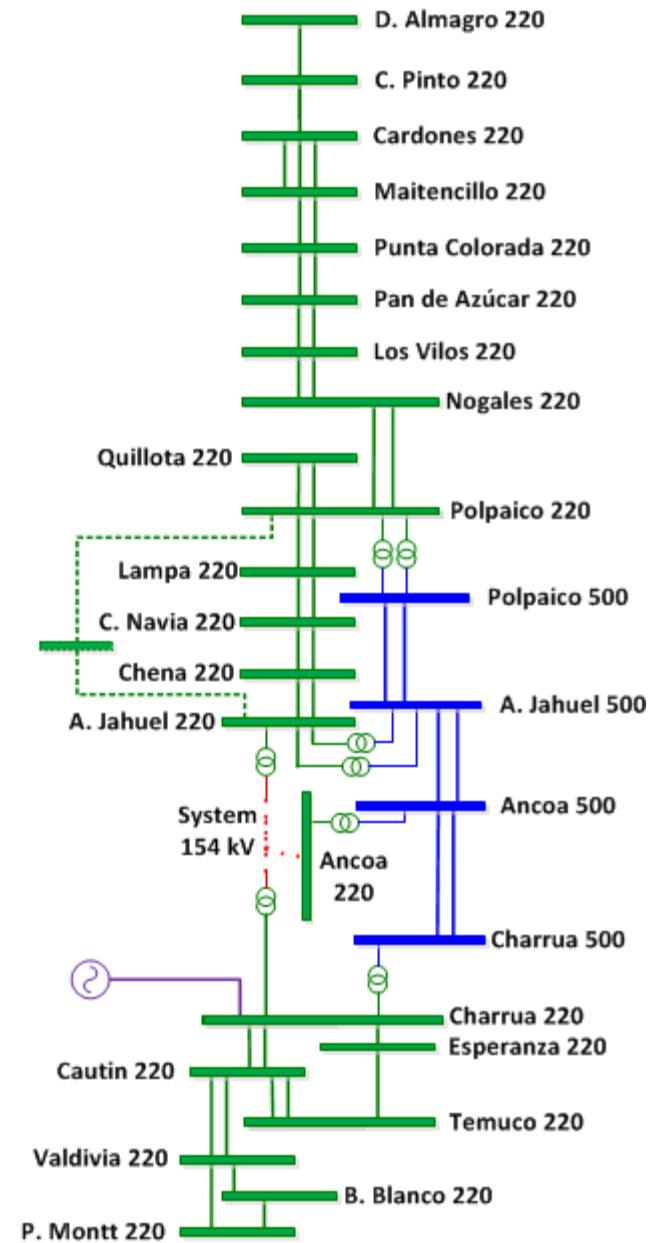
Magallanes isolated networks



Northern Interconnected System (SING)

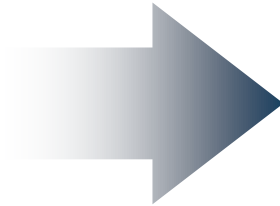


Central Interconnected System (SIC)



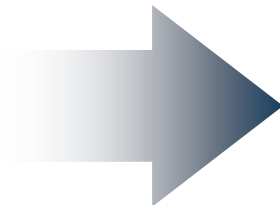
Regulatory Principles

Sufficiency & Efficiency
in the Long Term



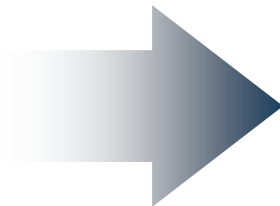
Long Term Energy
Contracts

Efficiency in the Short
Term and avoid Market
Power



Compulsory Pool and
Audited Costs

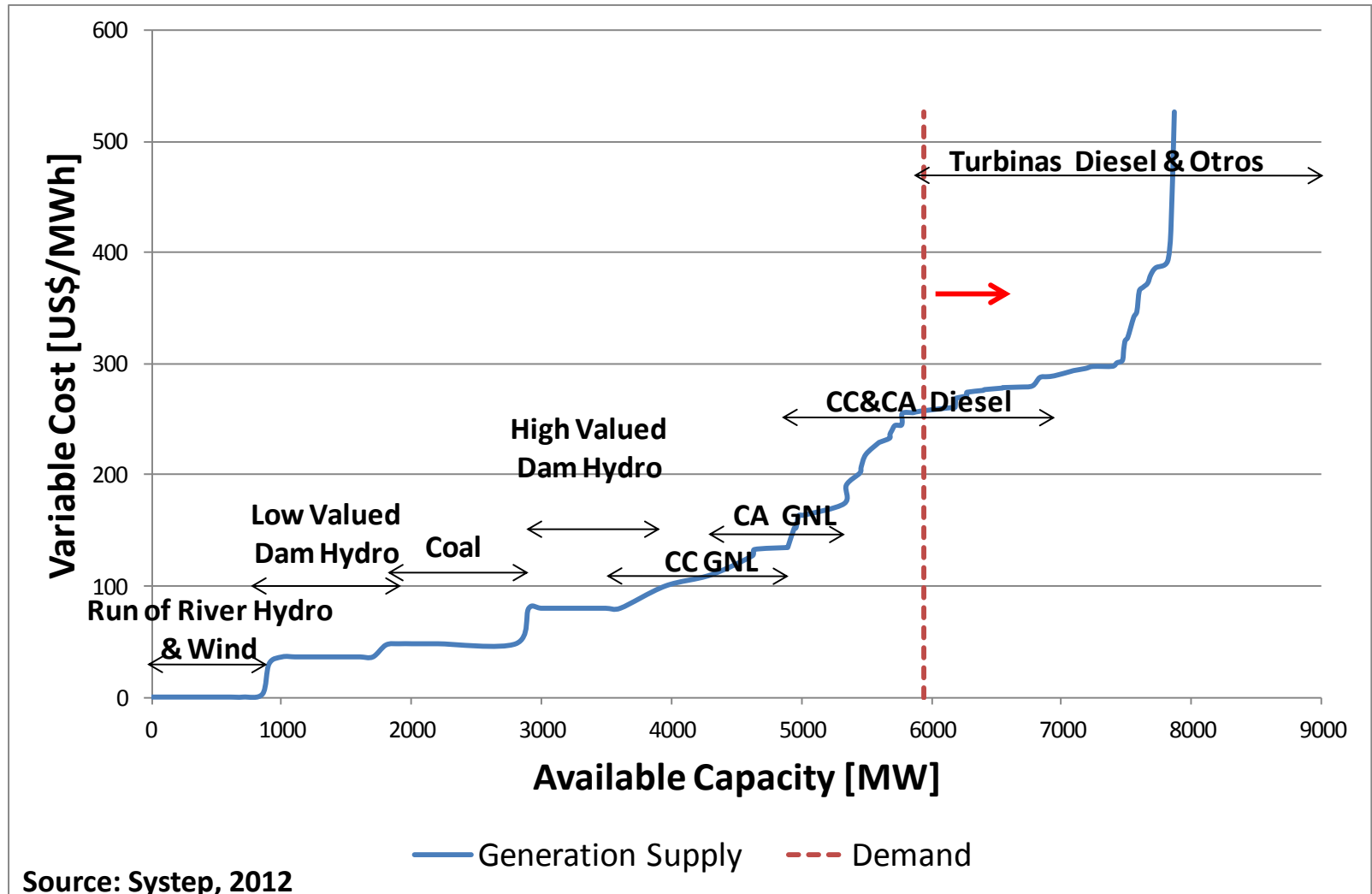
Adjustment between
Contracts and Minimum
Dispatch Cost



Spot Transfers among
Generators +
Capacity Charge

Market Operation by ISO

Dispatch Example

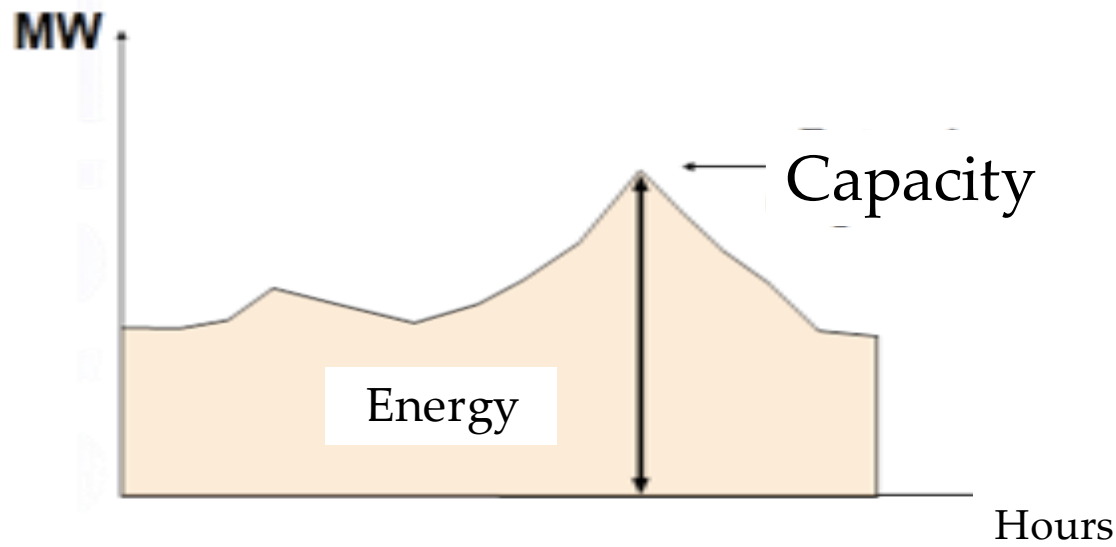


ISO completely independent of TO

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)

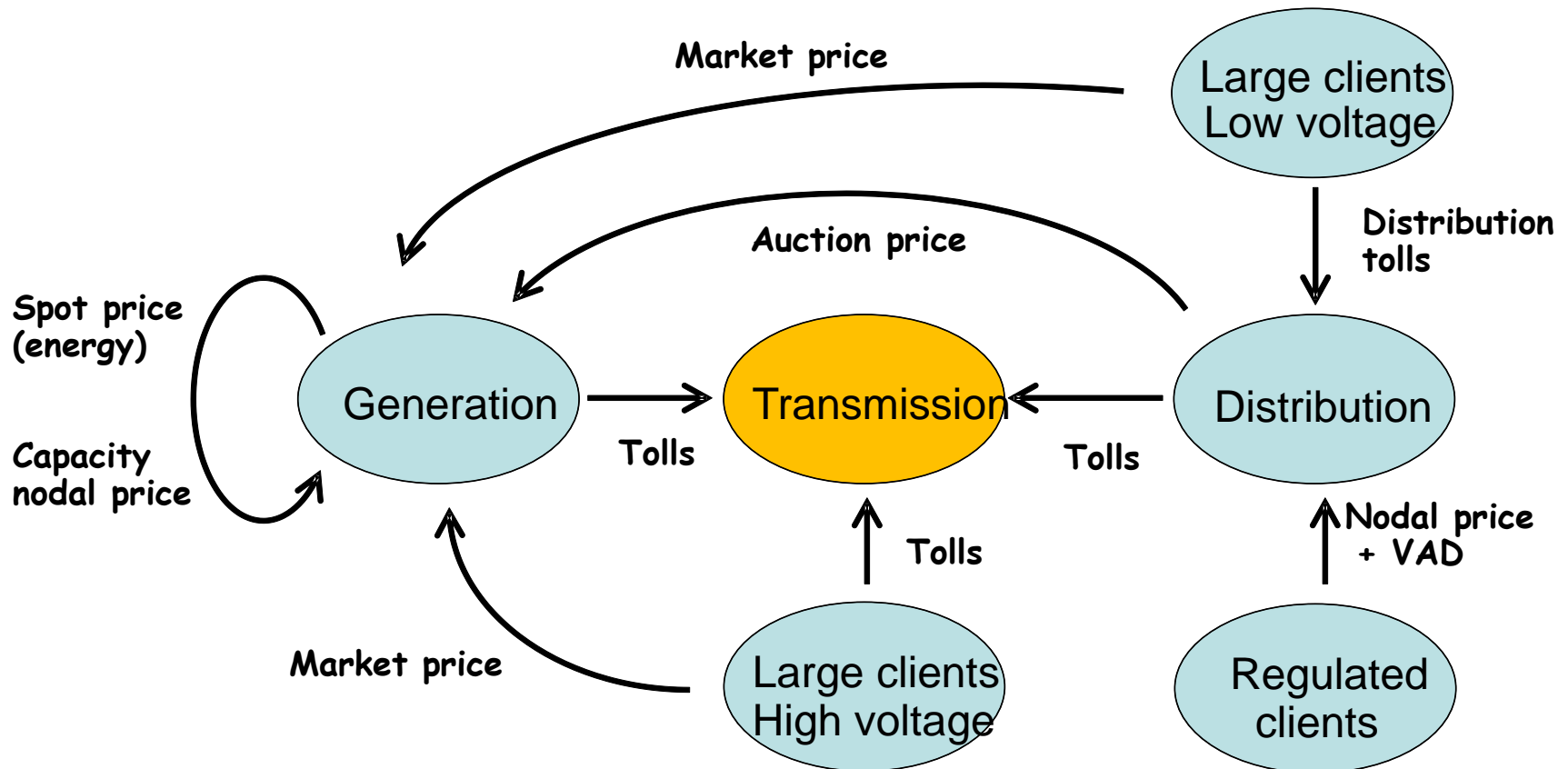


Generation fully contracted

- 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

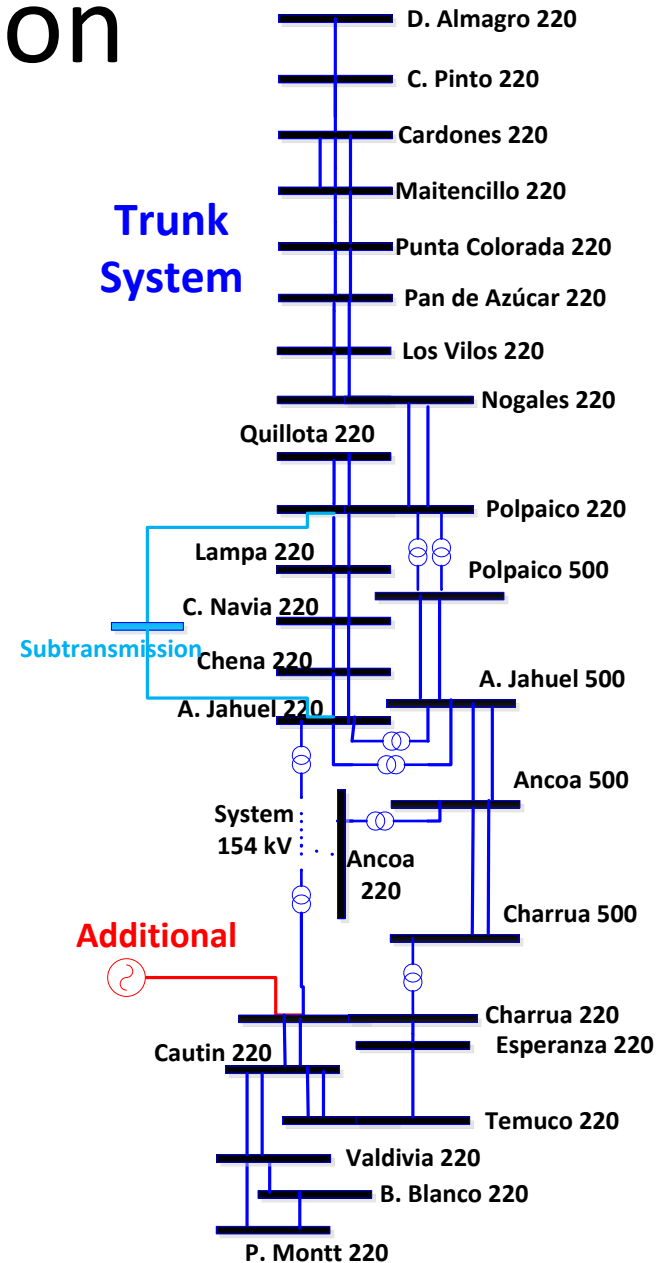


Transmission companies separate from ISO

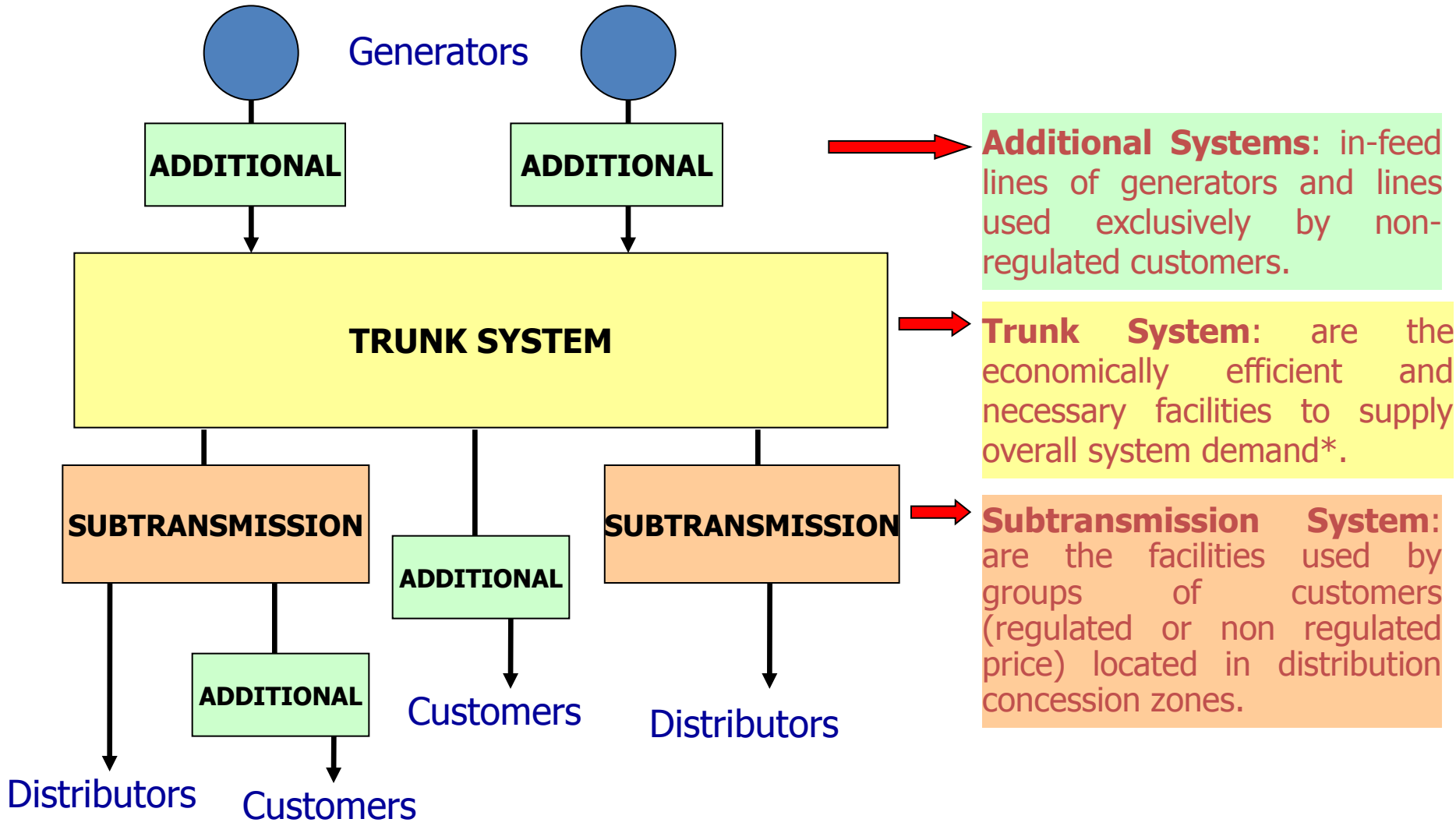
Transmission Regulation

➤ 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



Transmission Structure



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

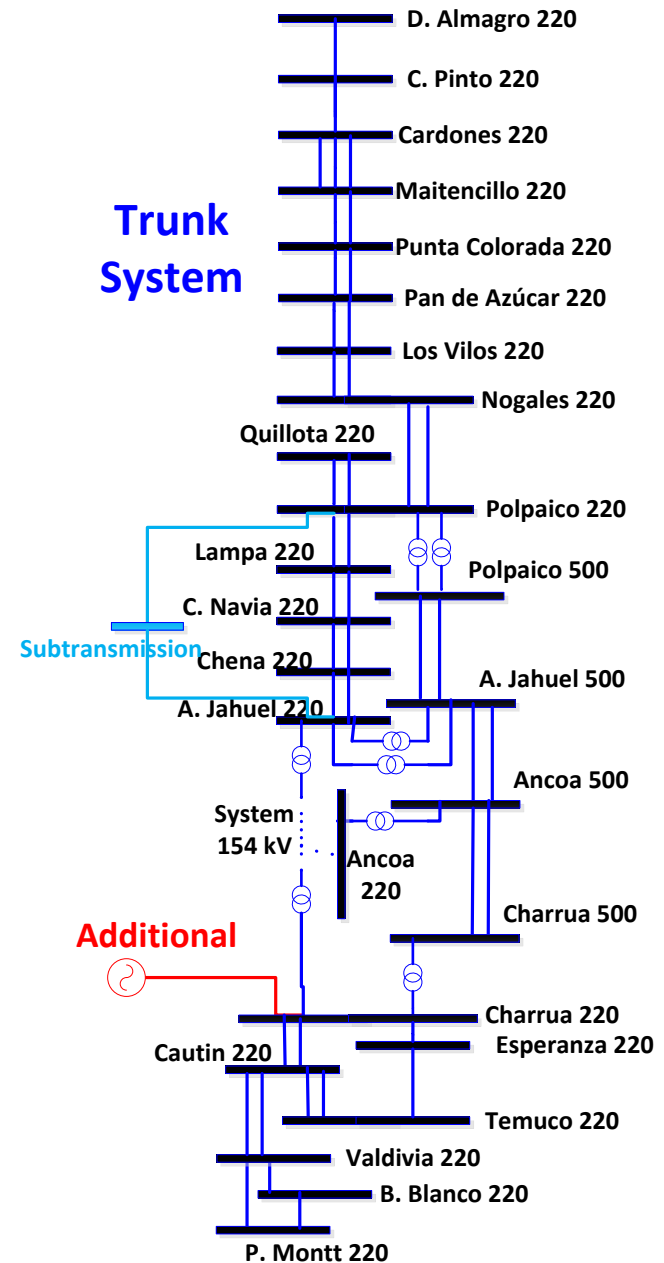
Trunk System: are the economically efficient and necessary facilities to supply overall system demand*.

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

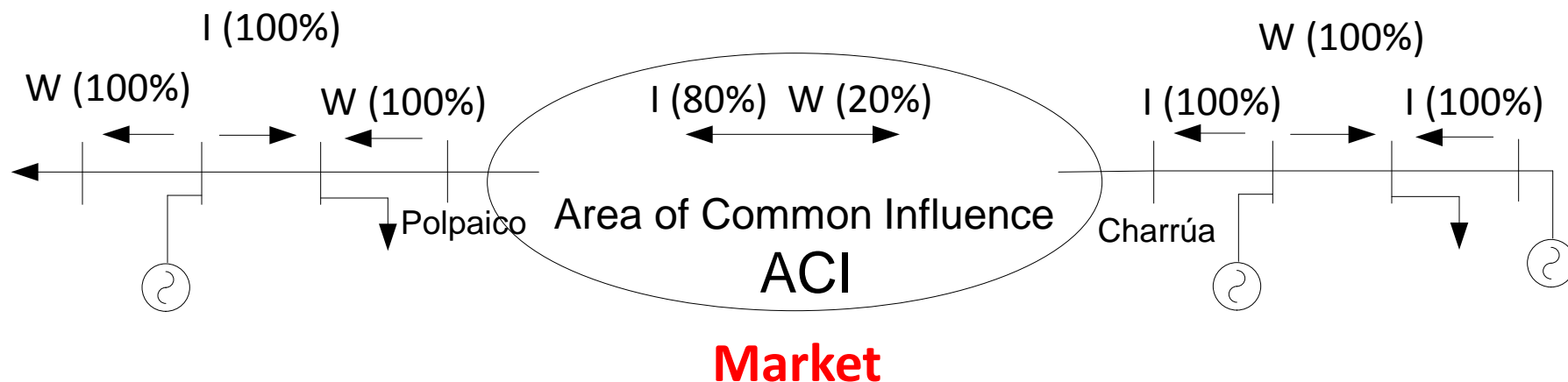
*defined by regulator every 4 years

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)



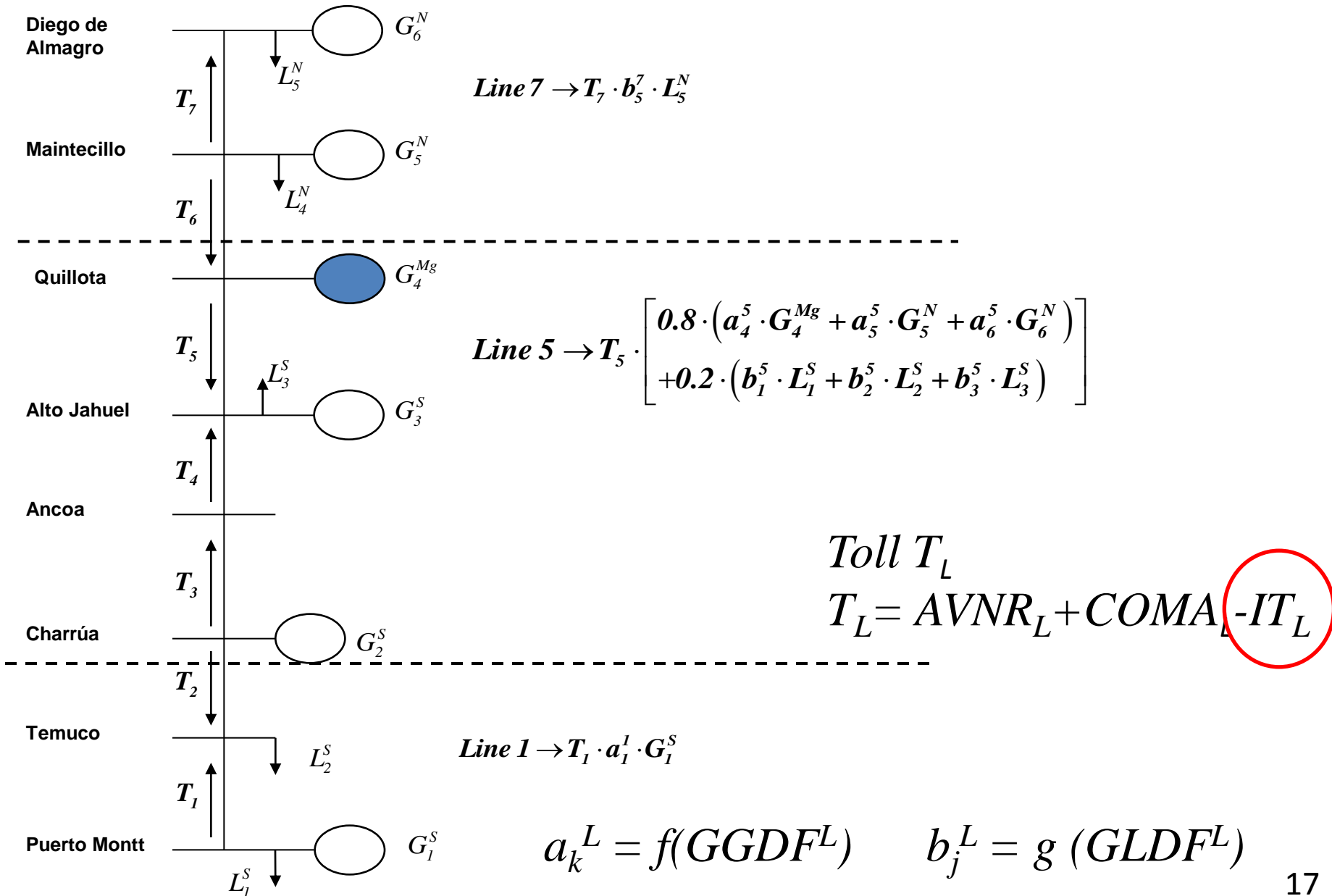
Transmission tolls



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

**Rudnick, H., Palma, R., Fernández, J. "Marginal pricing and supplement cost allocation in transmission open access". IEEE Transactions on Power Systems, Vol. 10, Nº2, May 1995, pp. 1125-1132

Transmission tolls



Nodal prices

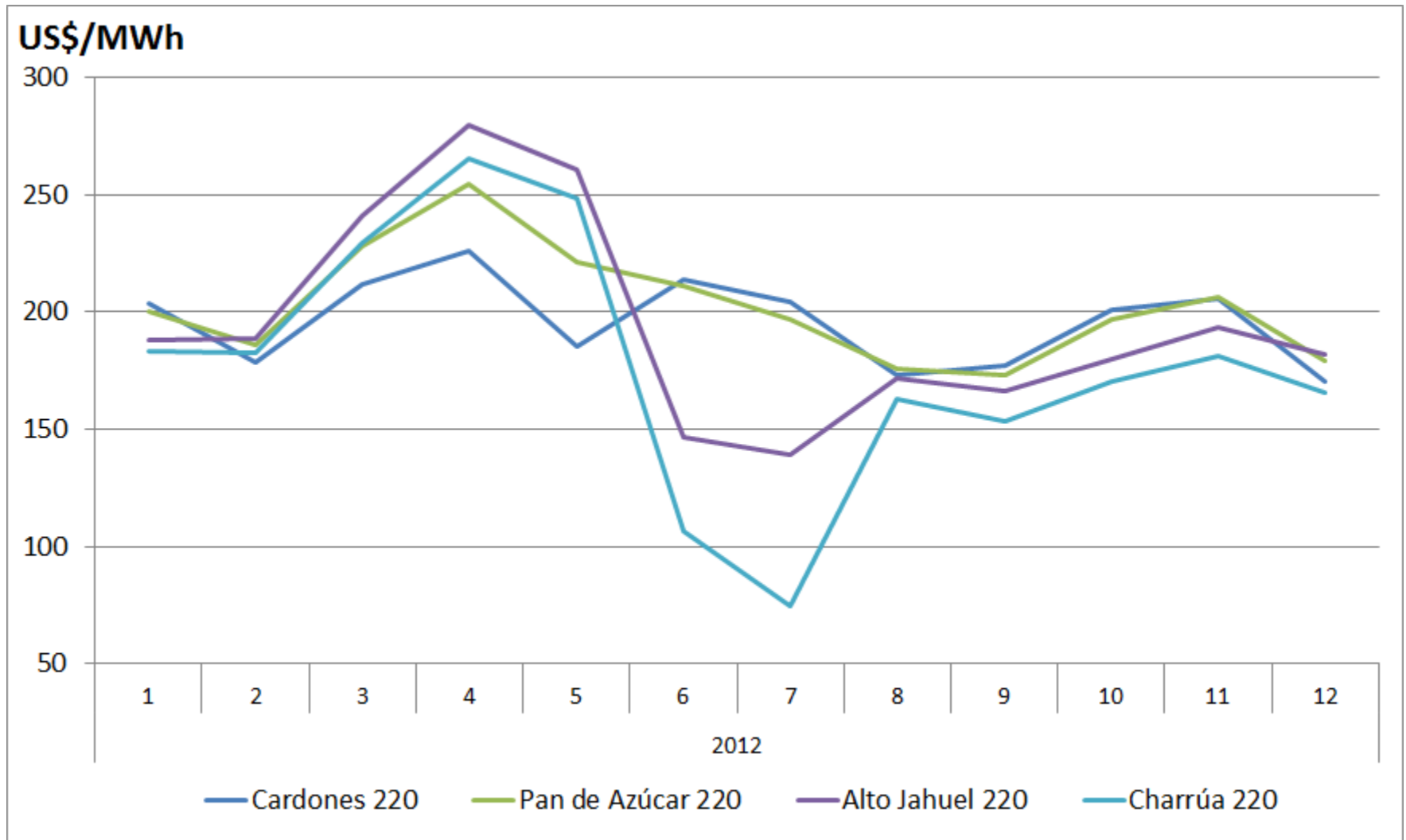
LMP

Short term locational spot prices reflecting:

- Generation costs
- Losses
- System congestion



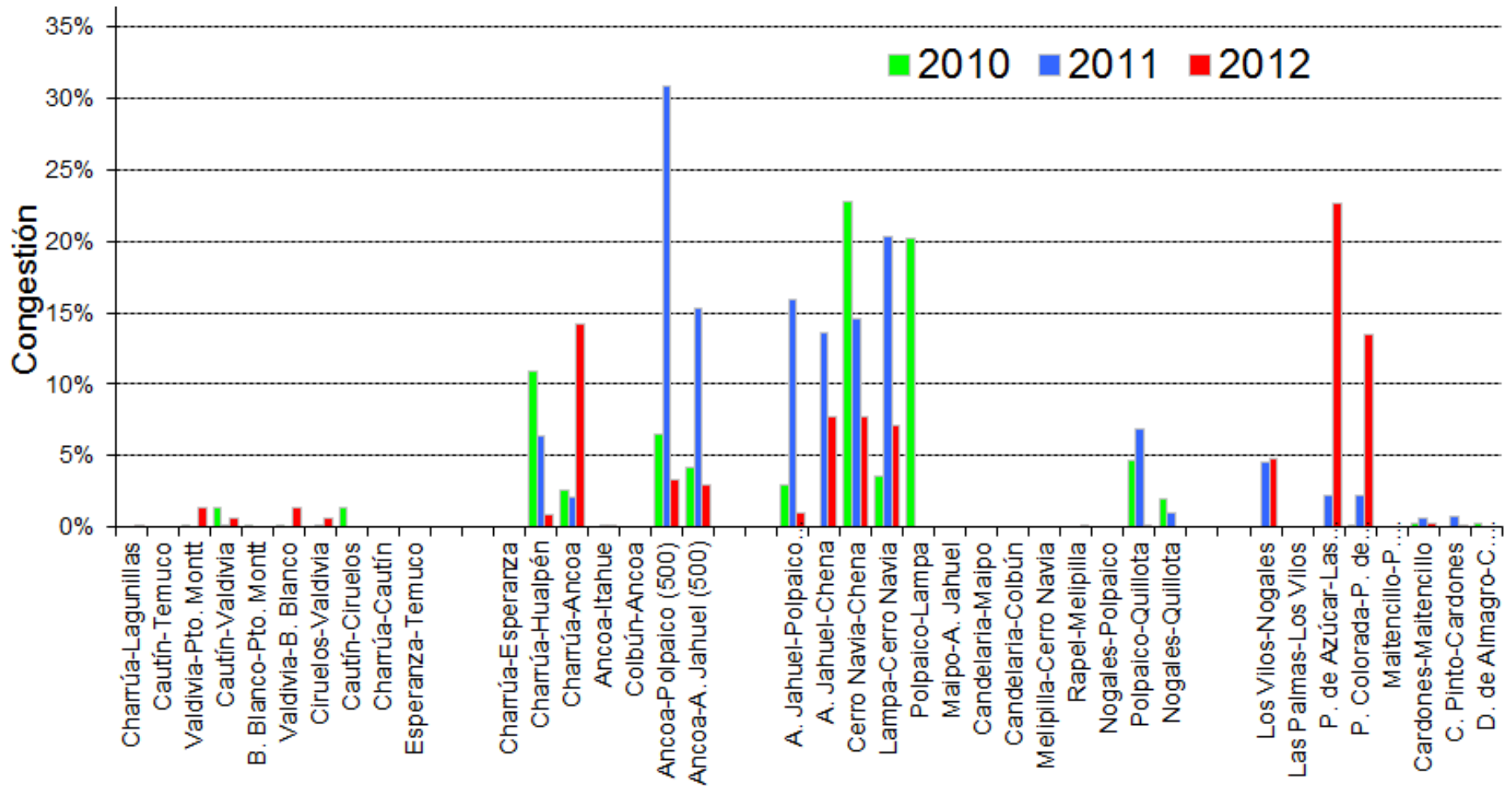
Nodal prices



SIC real LMP decoupling along 2012

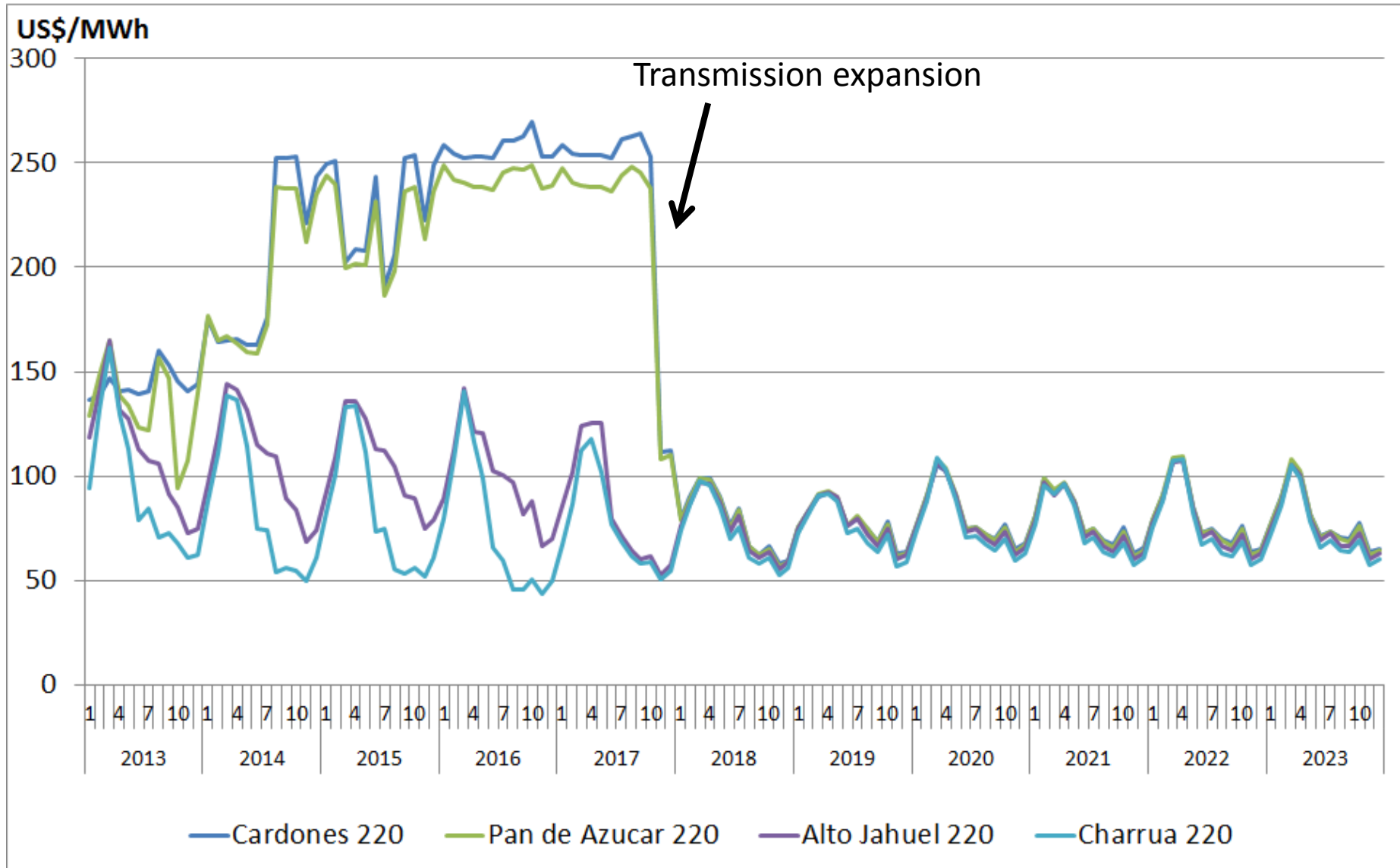
Congestion in trunk transmission

(2010-2012, % of hours a year)



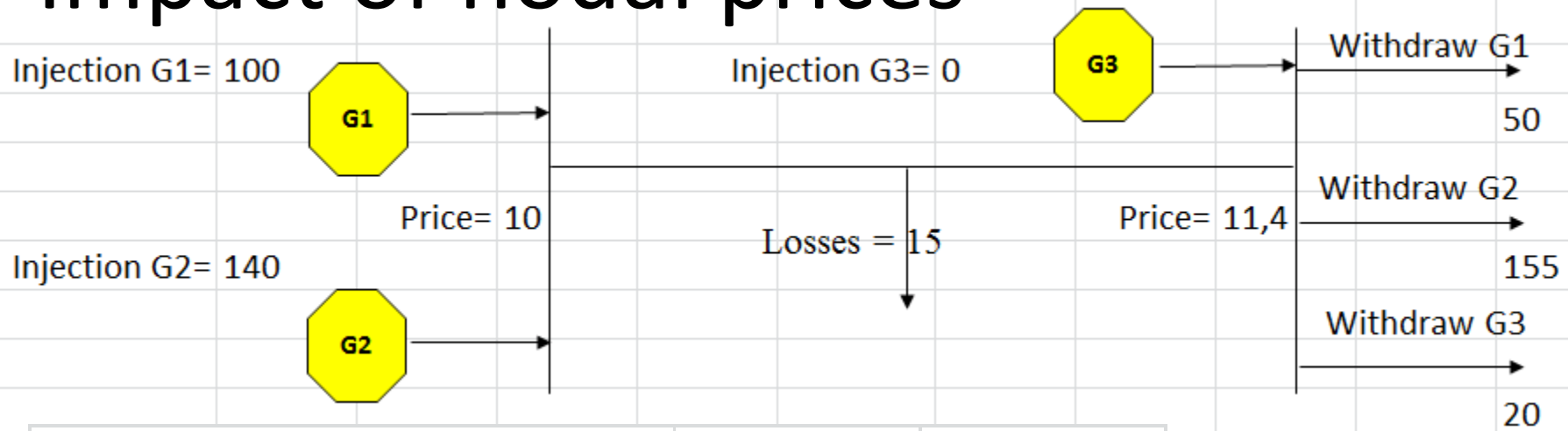
Ref.: Gener, Chile

Nodal prices



SIC projected LMP decoupling

Impact of nodal prices

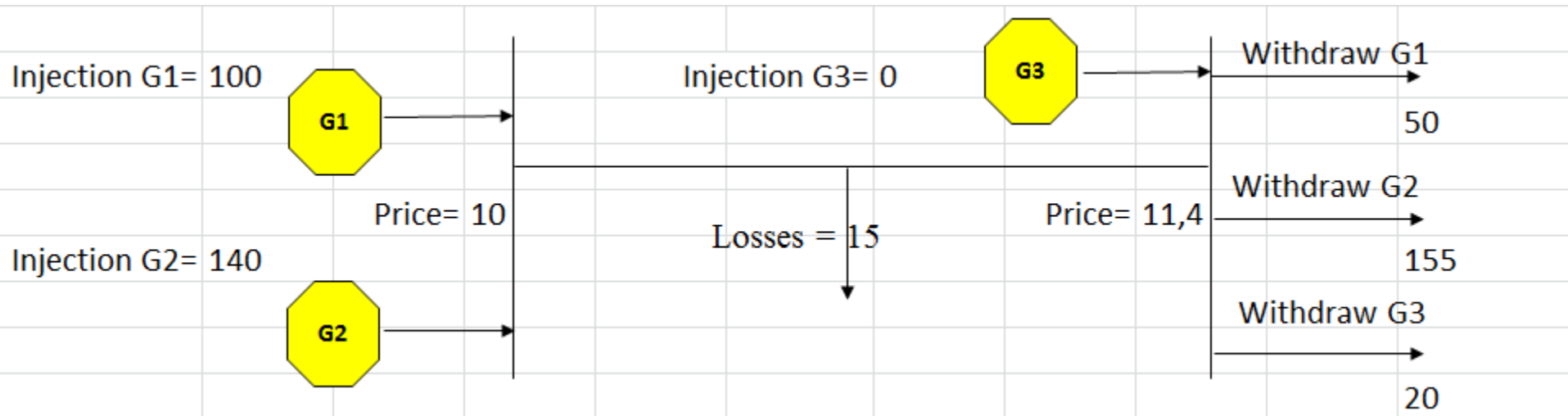


Valuation of injections

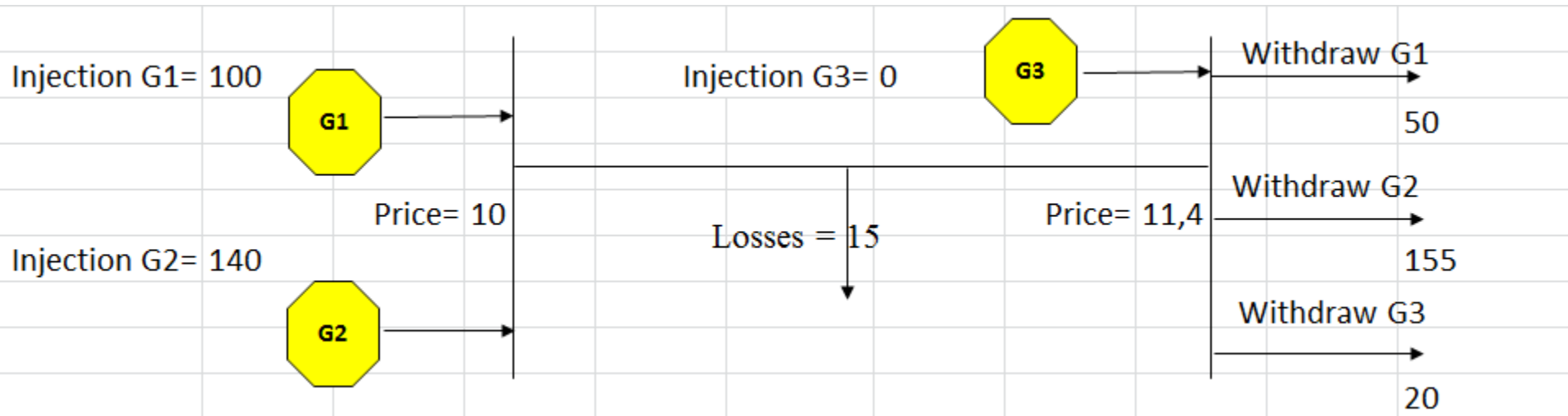
	Price	Injection	Value
G1	10,0	100,0	1000,0
G2	10,0	140,0	1400,0
G3	11,4	0,0	0,0
		240,0	2400,0

Valuation of withdrawals

	Price	Withdraw	Value
G1	11,4	50,0	571,4
G2	11,4	155,0	1.771,4
G3	11,4	20,0	228,6
		225,0	2.571,4

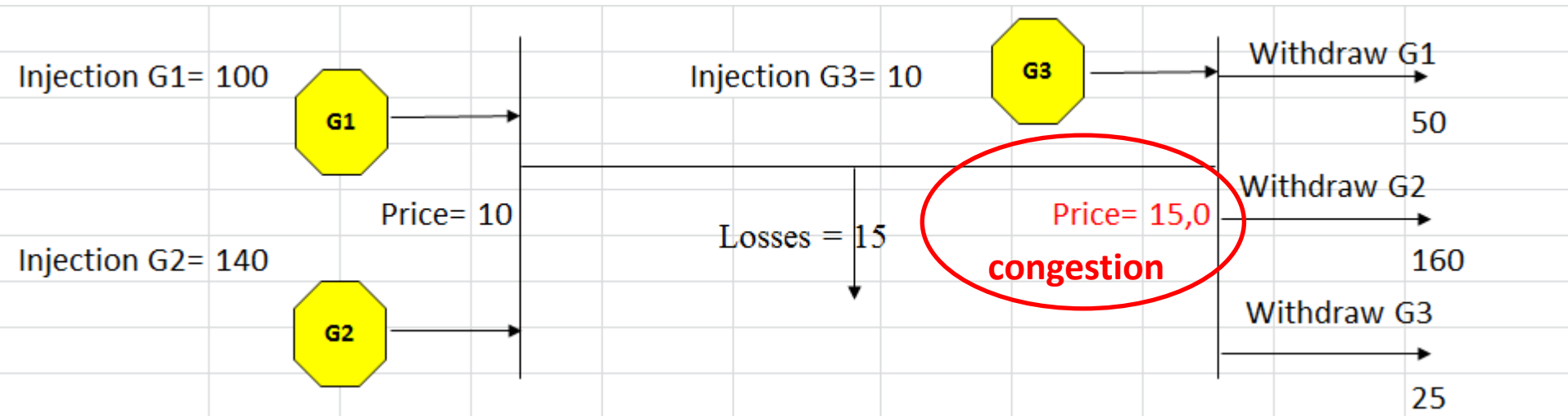


Balance	Physical	Valuation
G1	50,0	428,6
G2	- 15,0	- 371,4
G3	- 20,0	- 228,6
Total	15,0	- 171,4
Marginal rev	- 15,0	171,4



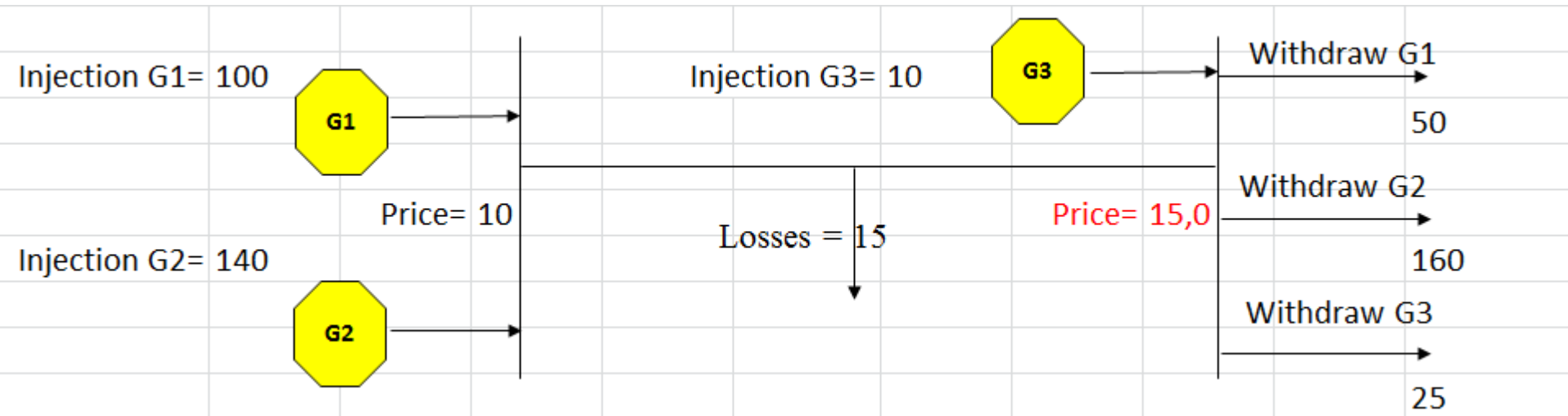
Transmission toll distribution		
	Flow	Percentage
G1	100,0	41,7%
G2	140,0	58,3%
G3		
Total	240,0	

Transmission toll	
Line value	500,0
Marginal rev	171,4
Toll payment	328,6
G1 payment	136,9
G2 payment	191,7

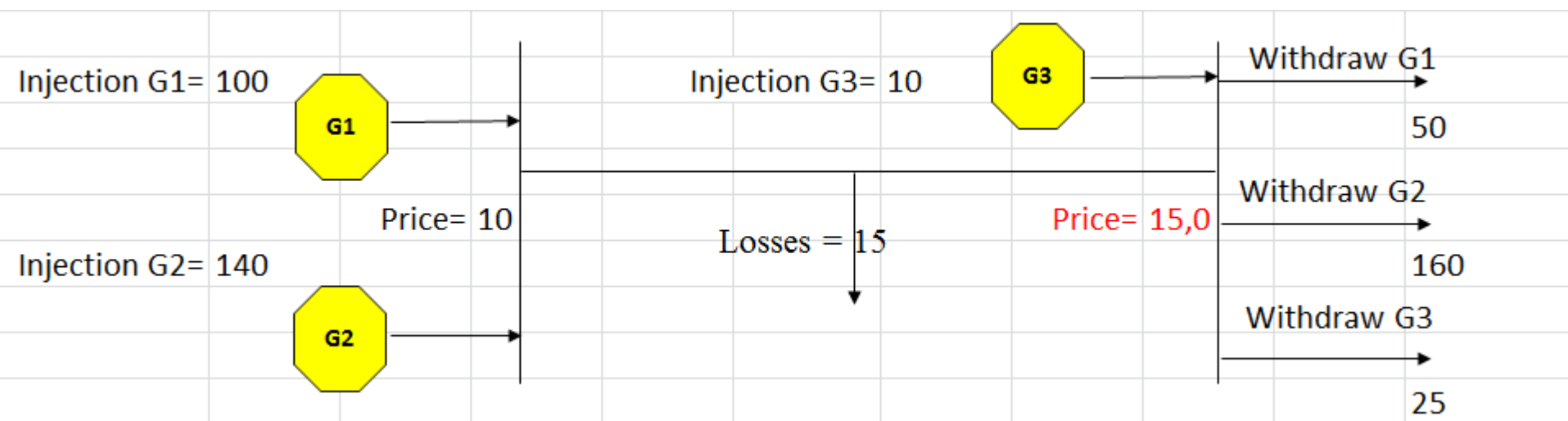


Valuation of injections			
	Price	Injection	Value
G1	10,0	100,0	1000,0
G2	10,0	140,0	1400,0
G3	15,0	10,0	150,0
		240,0	2550,0

Valuation of withdrawals			
	Price	Withdraw	Value
G1	15,0	50,0	750,0
G2	15,0	160,0	2.400,0
G3	15,0	25,0	375,0
		235,0	3.525,0



Balance	Physical	Valuation
G1	50,0	250,0
G2	- 20,0	- 1.000,0
G3	- 15,0	-
Total	15,0	- 750,0
Marginal rev	- 15,0	750,0



Transmission toll distribution		
	Flow	Percentage
G1	100,0	41,7%
G2	140,0	58,3%
G3		
Total	240,0	

Transmission toll	
Line value	500,0
Marginal rev	750,0
Toll payment	- 250,0
G1 payment	- 104,2
G2 payment	- 145,8

2010 SIC Balance of injections and withdrawals

Empresa	Transferencias de Energía ⁽¹⁾		Otros Pagos \$	Devoluciones IT \$	Transferencias de Potencia \$	Total Valorizado \$
	Físico kWh	Valorizado \$				
ENDESA	207.586.526	-65.962.772.300	-593.207.780	22.381.168.371	-19.195.498.945	-63.370.310.653
GENER	-1.000.166.876	-110.497.288.717	-692.743.139	8.083.842.554	-14.684.757.606	-117.790.946.909
COLBUN	544.982.471	12.974.645.316	-762.217.252	11.348.844.948	8.282.170.802	31.843.443.813
PEHUENCHE	747.407.883	43.479.131.595	-8.890.359	0	706.790.700	44.177.031.936
GUACOLDA	984.293.570	46.107.682.621	-963.352.541	1.755.932.025	-6.578.066.520	40.322.195.585
ARAUCO	369.904.954	26.284.694.886	36.485.887	796.065.135	3.151.729.911	30.268.975.819
ESSA	481.336.040	40.730.028.035	2.560.921.465	92.436.502	4.077.500.376	47.460.886.377
TRANSELEC	-416.676.121	38.672.990.026	0	0	7.676.228.353	46.349.218.379
STS	-1.672.533	166.436.467	0	0	-49.555	166.386.911
IBENER	20.712.889	-456.960.402	-52.151.975	993.578.187	628.551.690	1.113.017.499
SGA	-29.751.111	1.055.015.853	930.189.026	670.592.386	1.279.333.568	3.935.130.832
PUYEHUE	117.560.046	10.192.727.173	-24.860.462	79.195.303	43.825.278	10.290.887.291
CTNC	-40.903.783	3.823.130.552	0	0	74.698.340	3.897.828.892
CAMPANARIO	-1.179.575.887	-94.190.895.548	-130.196.779	4.848.872.321	-4.795.890.336	-94.268.110.342
SC DEL MAIPO	10.310.314	611.437.858	-10.476.290	88.122.289	-160.052.261	529.031.597
TECNORED	-6.818.668	-313.332.561	-5.731.761	10.574.230	506.180.303	197.690.211
NUEVA ENERGIA	-48.714.043	-3.777.447.464	-45.431.675	393.577.035	-34.231.158	-3.463.533.261
ELEKTRAGEN	3.008.698	370.950.038	3.457.032	0	1.122.349.068	1.496.756.138
POTENCIA CHILE	-11.208.340	-812.249.285	-2.507.380	12.867.494	3.043.836.386	2.241.947.215
GESAN	6.660.616	479.799.876	0	0	16.434.546	496.234.421
PACIFIC HYDRO	-313.479.514	-21.413.689.071	-64.705.825	196.298.460	-1.874.973.530	-23.157.069.967

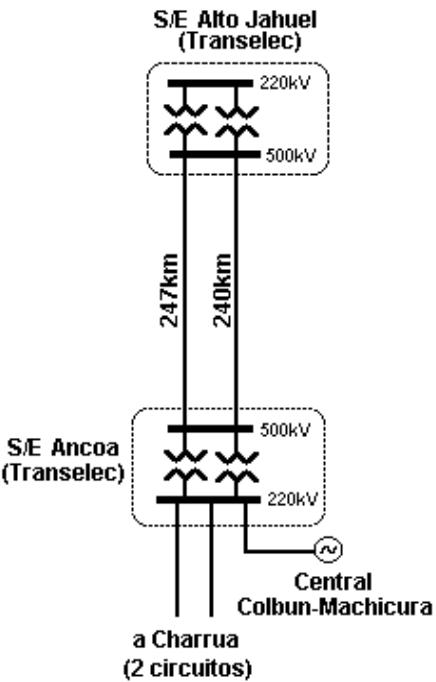
ORIGINAL EXPANSION REGULATION

1982-2003

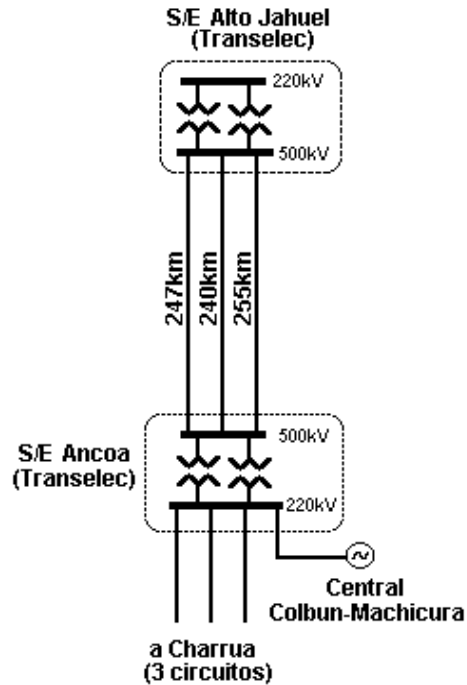
- Only generators pay for transmission, use of system approach
- Market oriented transmission toll regulation
 - Two party negotiations, no coherency checks for the global system
 - Different understanding of area of influence
 - High transaction costs and barriers of entry to new investors
 - Remuneration 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

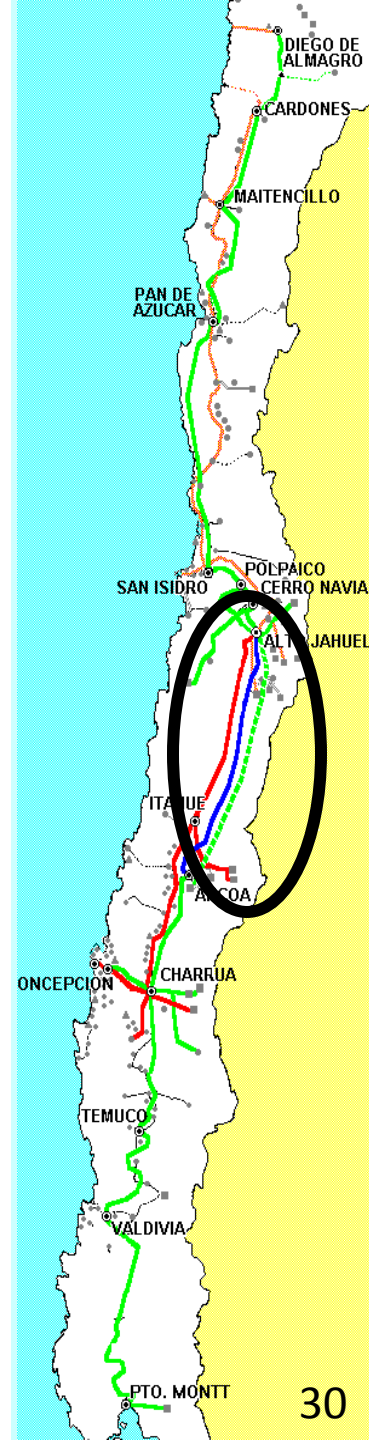
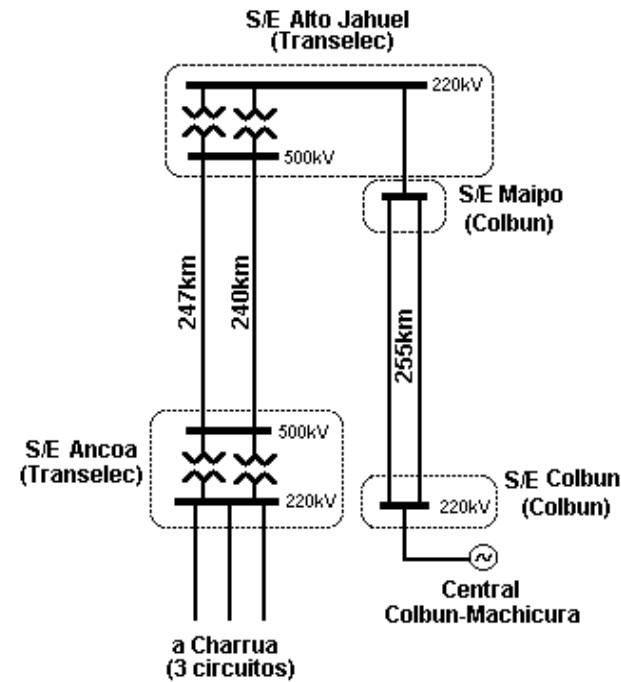
1996 system



Transec expansion proposal



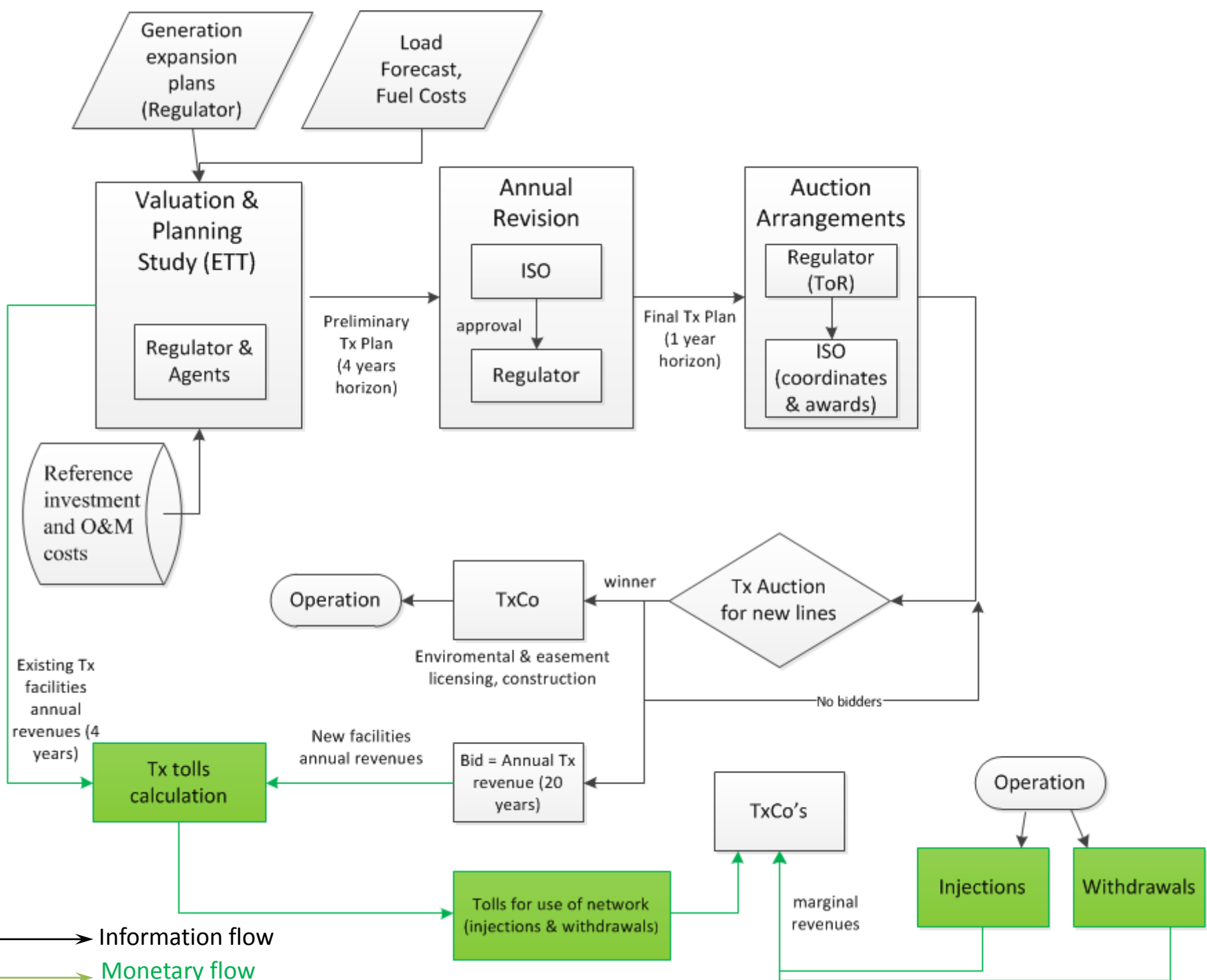
Colbun solution 1997

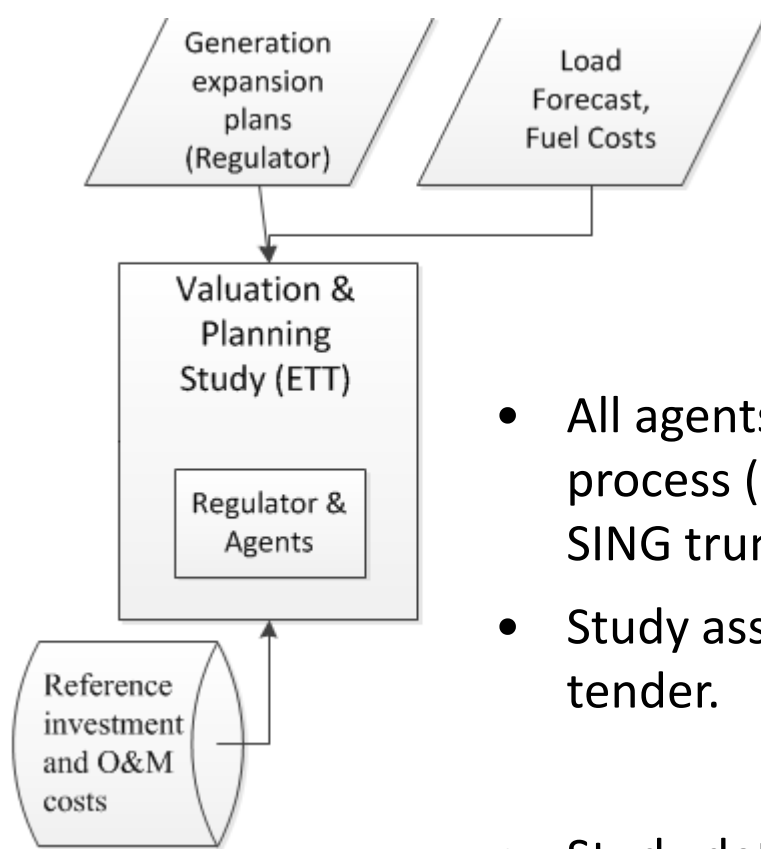


NEW TRANSMISSION EXPANSION

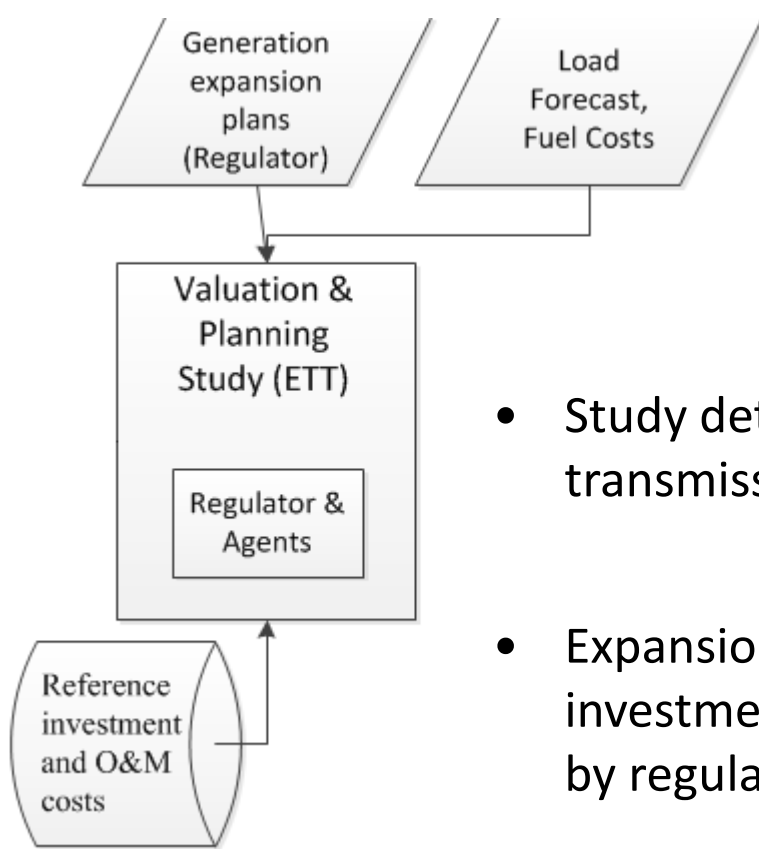
2004

- 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.





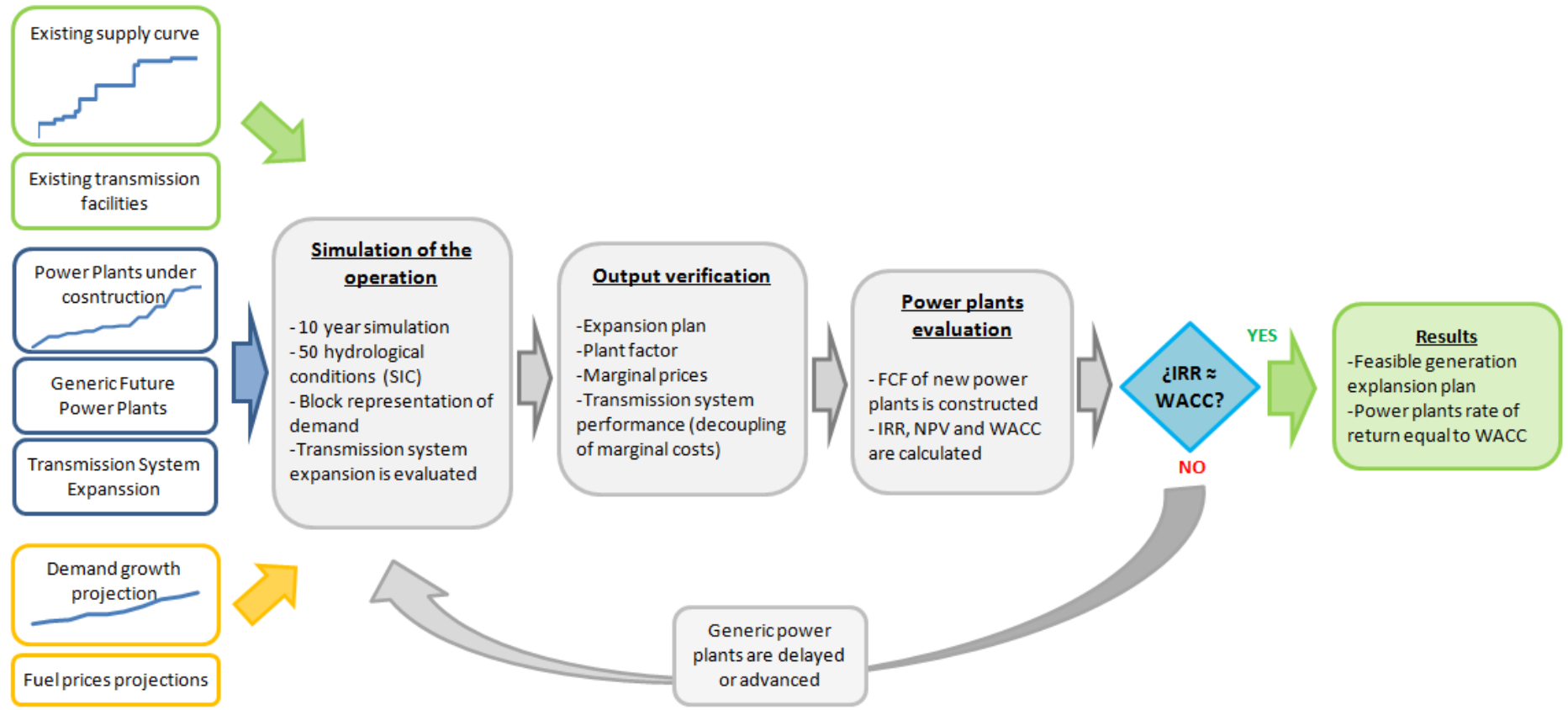
- All agents participate in the study via a consultation process (Regulator, SIC and SING gencos, SIC and SING trunk transcos, discos and large consumers).
- Study assigned to consultant through international tender.
- Study determines the trunk system VI (investment), COMA (operation), Economic Life 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.

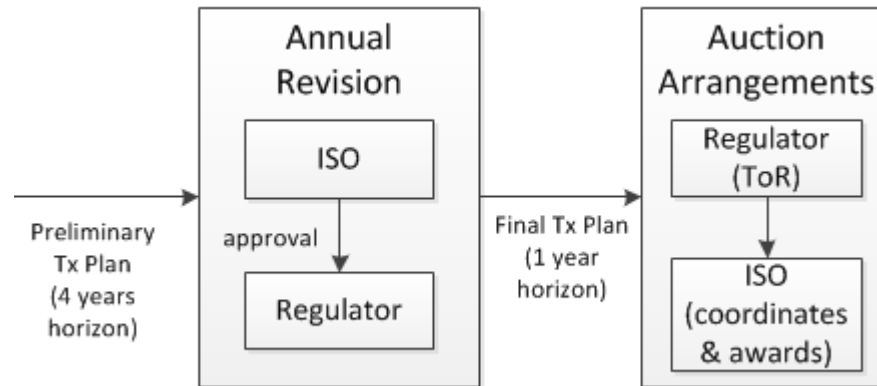
Generation expansion plans (indicative)

Investment model

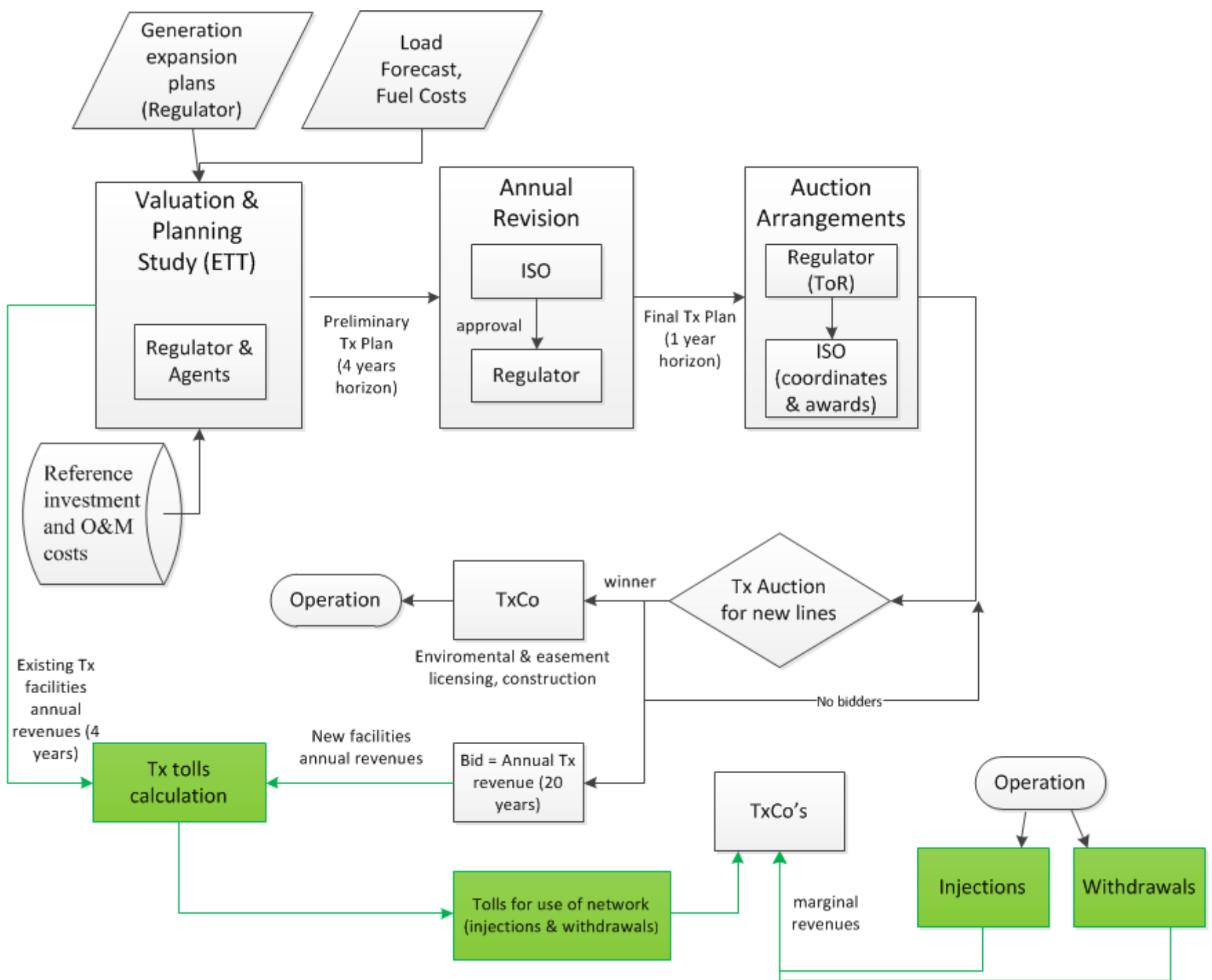


Minimizing investment + operation + unserved energy under competitive environment

Need to consider uncertainties on hydro energy production in SIC

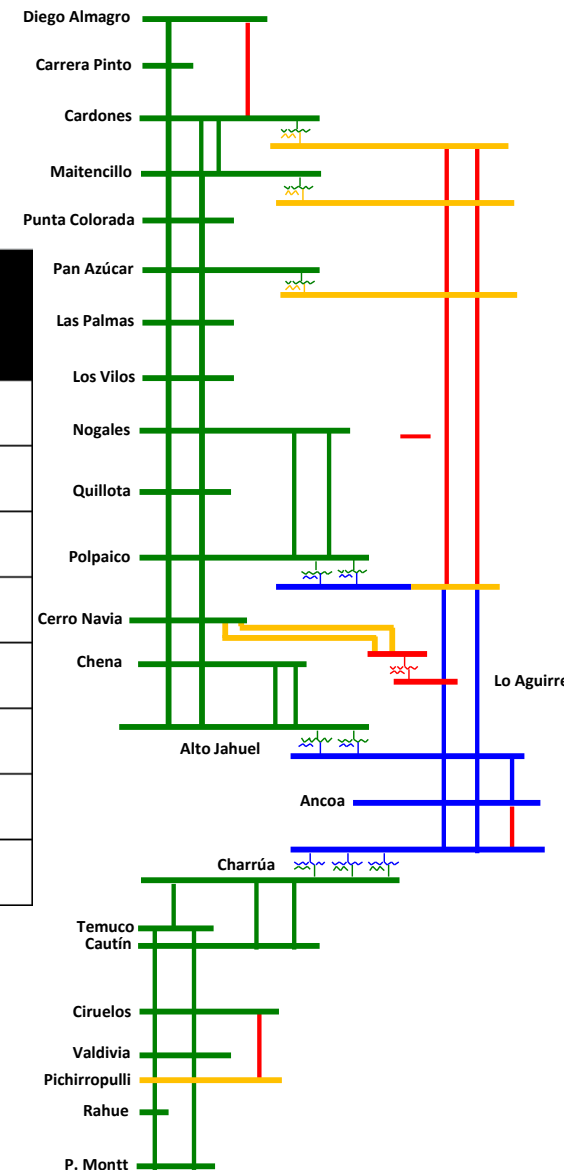


- The expansion plan is revised and adapted by the operator every year and the regulator defines the definitive plan. All agents participate in the revision.
- The trunk system expansion projects may be upgrades of the existing system or new projects:
 - Upgrades of the existing system are assigned directly 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

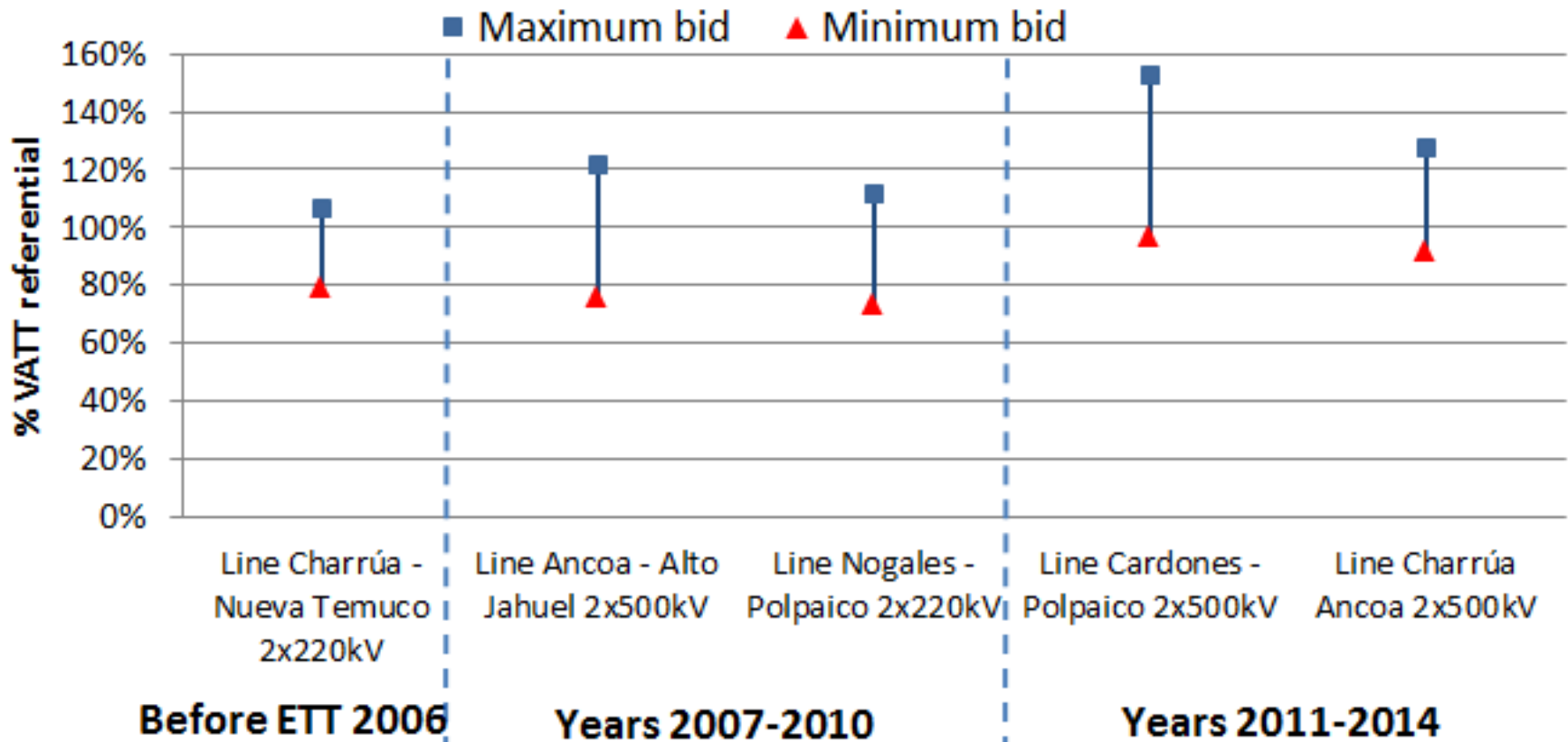


#	Project	V_{ref} (MMUSD)	Length (km)	COMA (%)	Bidders
1	Subestación Seccionadora Lo Aguirre	69,02	-	1,44	5
2	Charrúa – Ancoa 2x500 kV (1C)	140,40	196,55	1,44	3
3	Pan de Azúcar –Polpaico 2x500 kV	280,00	401,80	1,5	5
4	Maintencillo-Pan de Azúcar 2x500 kV	130,11	209,20	1,58	5
5	Cardones – Maintencillo 2x500 kV	79,32	132,40	1,44	5
6	Cardones – Diego Almagro 2x220 kV (1C)	37,00	152,00	2,07	5
7	Ciruelos – Pichirropulli 2x220 kV (1C)	45,49	83,00	2,07	2
8	CER 100/-60 MVaR S/E Cardones	20,70	-	2,07	3

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

Transmission system expansion

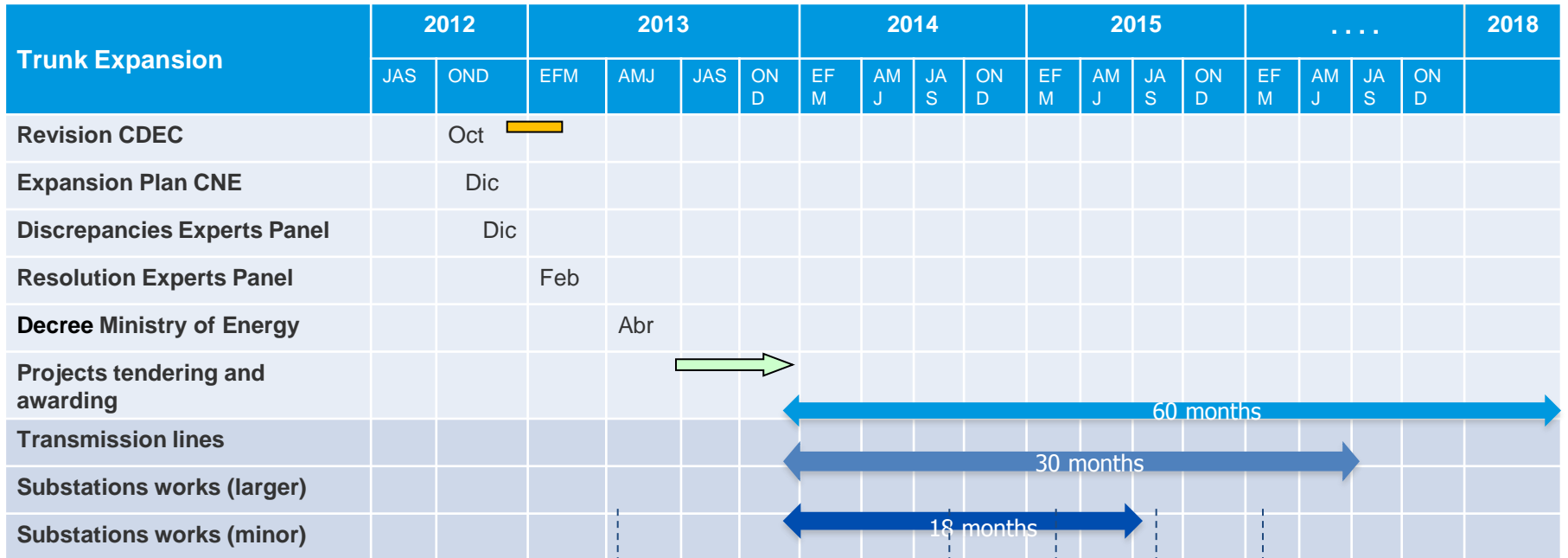
SIC auction process- bids for main lines



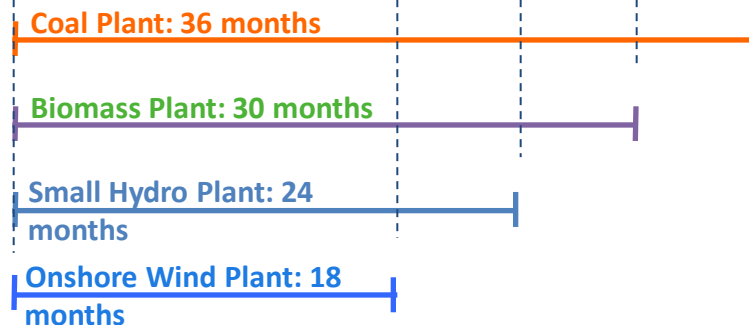
Construction of new installations

- 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

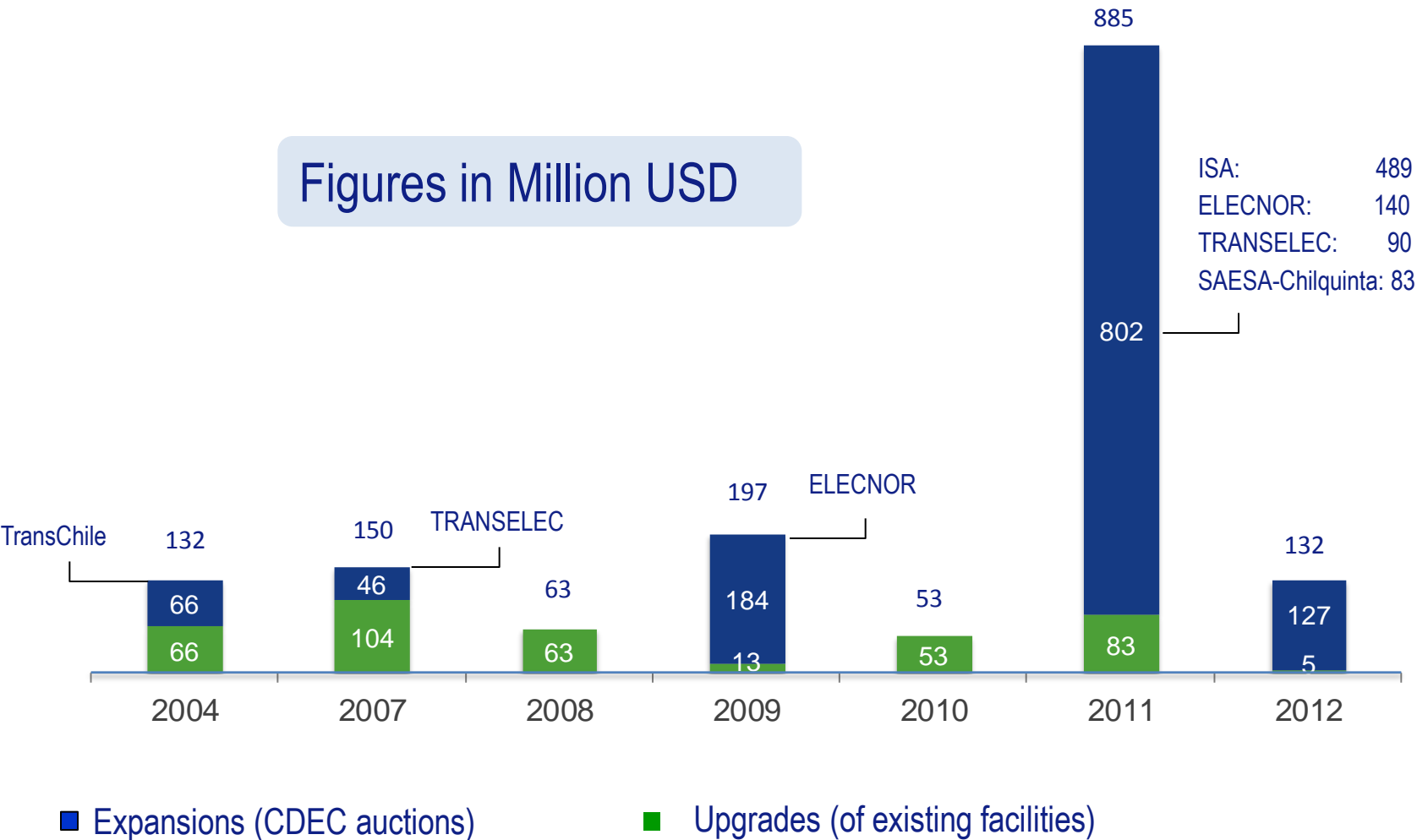


Source: JC Araneda, Transelec



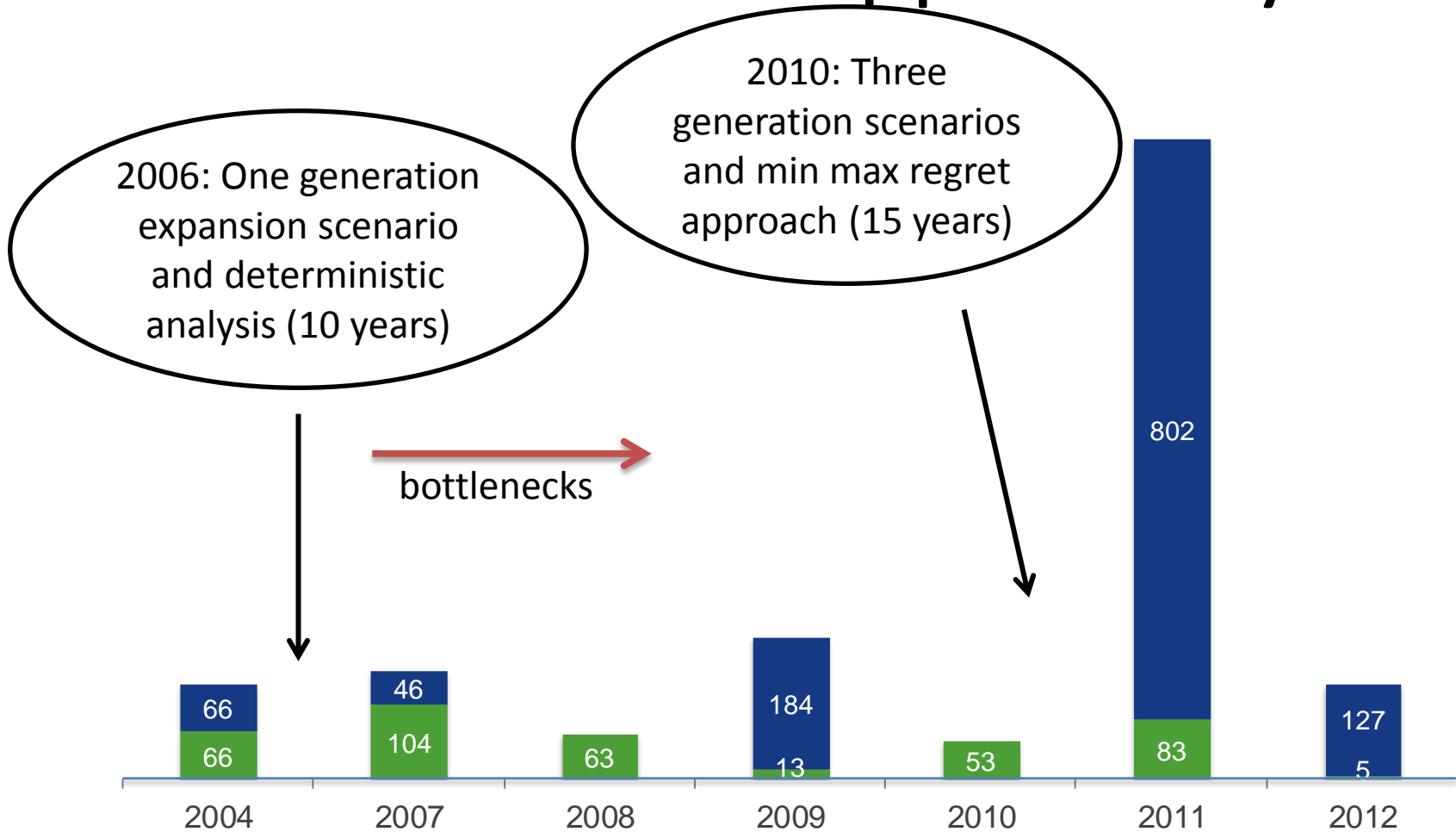
Dynamic market plus long environmental approval process and RoW negotiations require faster transmission expansion decisions for generation projects to develop.

Uncertainties and opportunity



Source: JC Araneda, Transelec

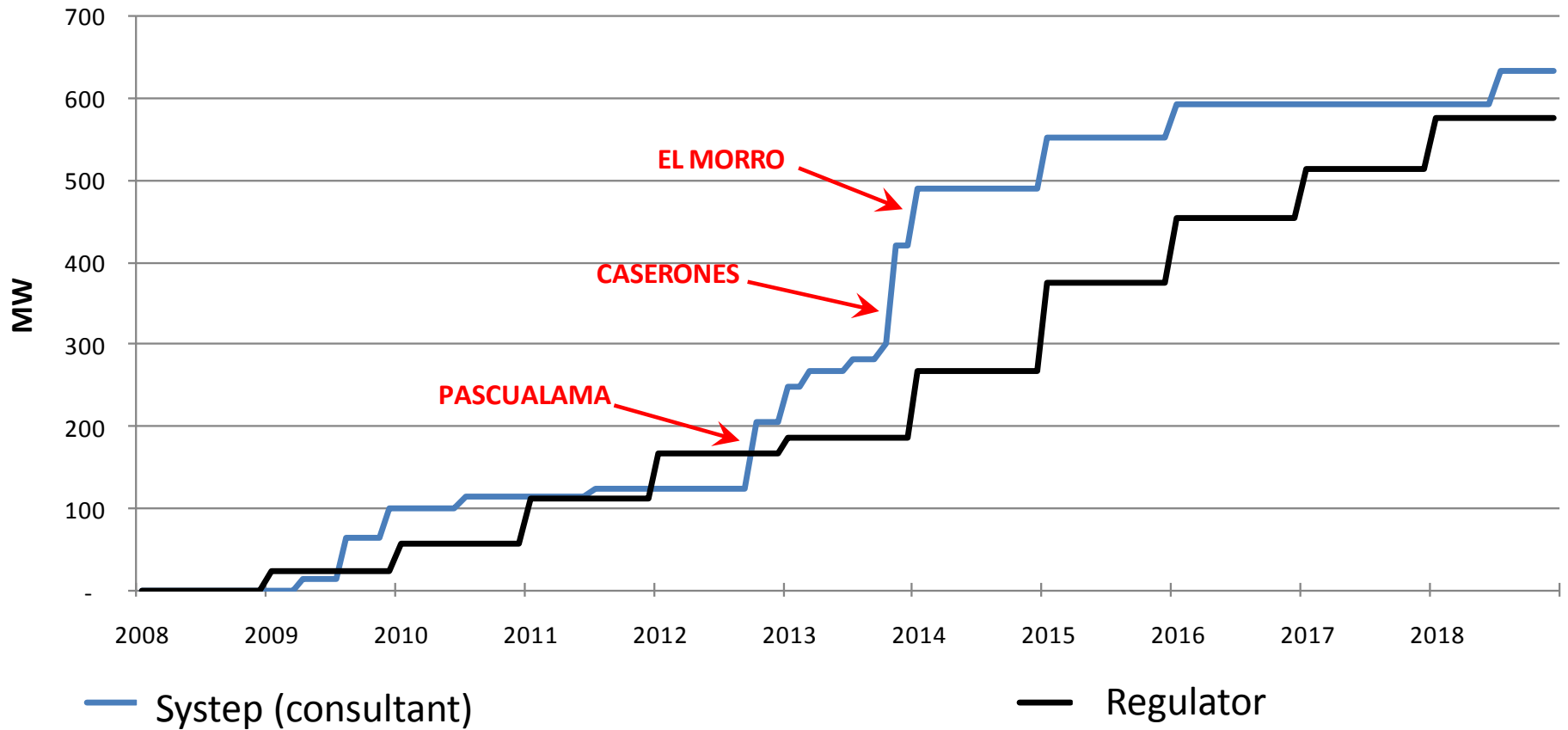
Uncertainties and opportunity in ETT



Investment value [MMUSD]			
ETT Study	Lines	Substations	Total
2006	139,7	-	139,7
2010	712,3	89,7	802,0

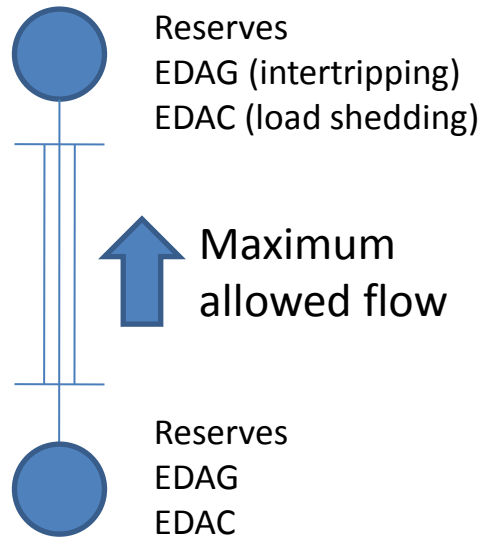
Load uncertainties

Timing of new mining projects in northern SIC

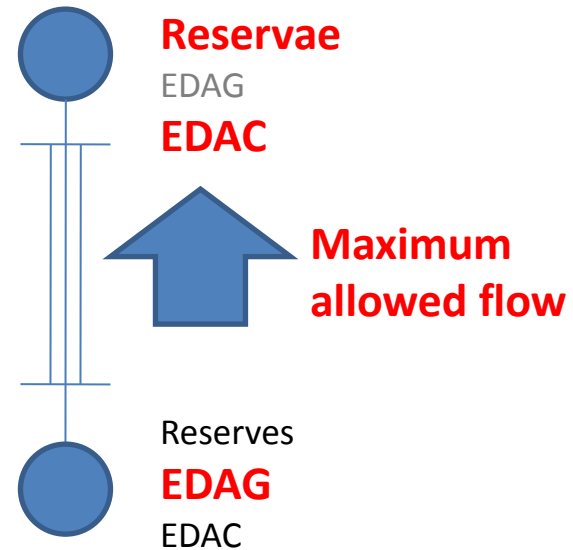


How much use of *smart* options?

Basic system operation



Operation with smart control



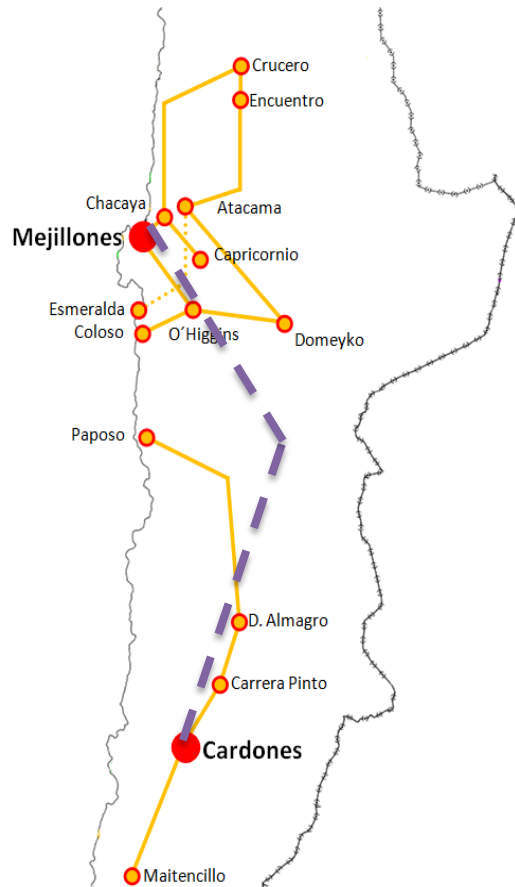
System n-1 security may be incremented through smart control schemes

Diverge positions at ISO, based on cost impacts.

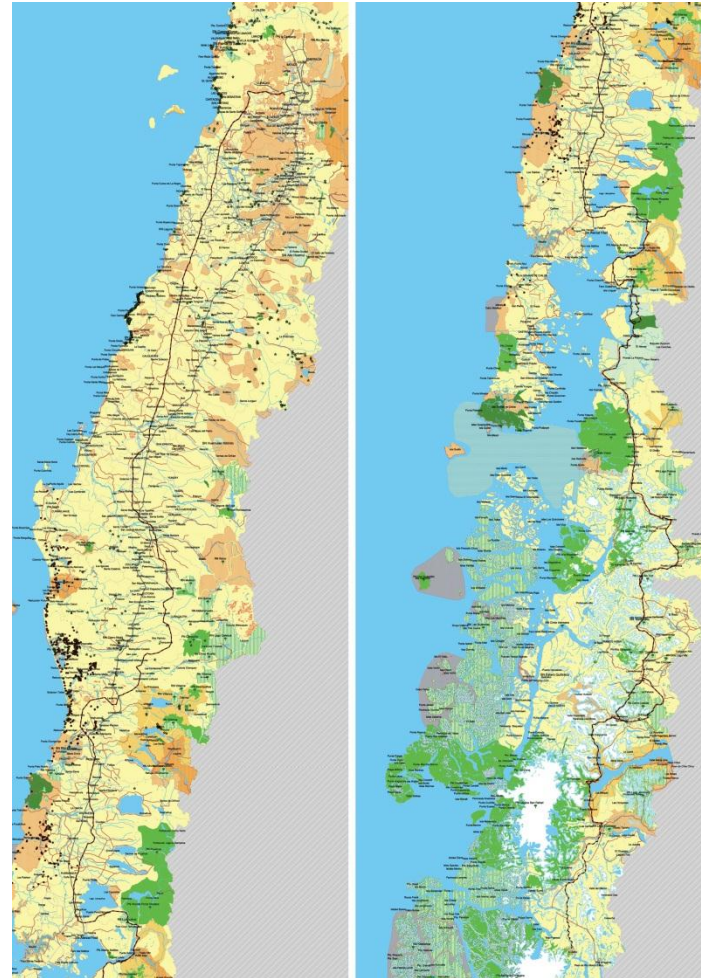
Some difficulties and challenges

- Dissociation between competitive generation market and centralized transmission planning (Experts panel solving controversies)
 - Conflicting 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

Fourth line



Several years delay to much needed Fourth Line from Comahue (major generation source) to Buenos Aires (major demand center)

Congestion increasing on corridor

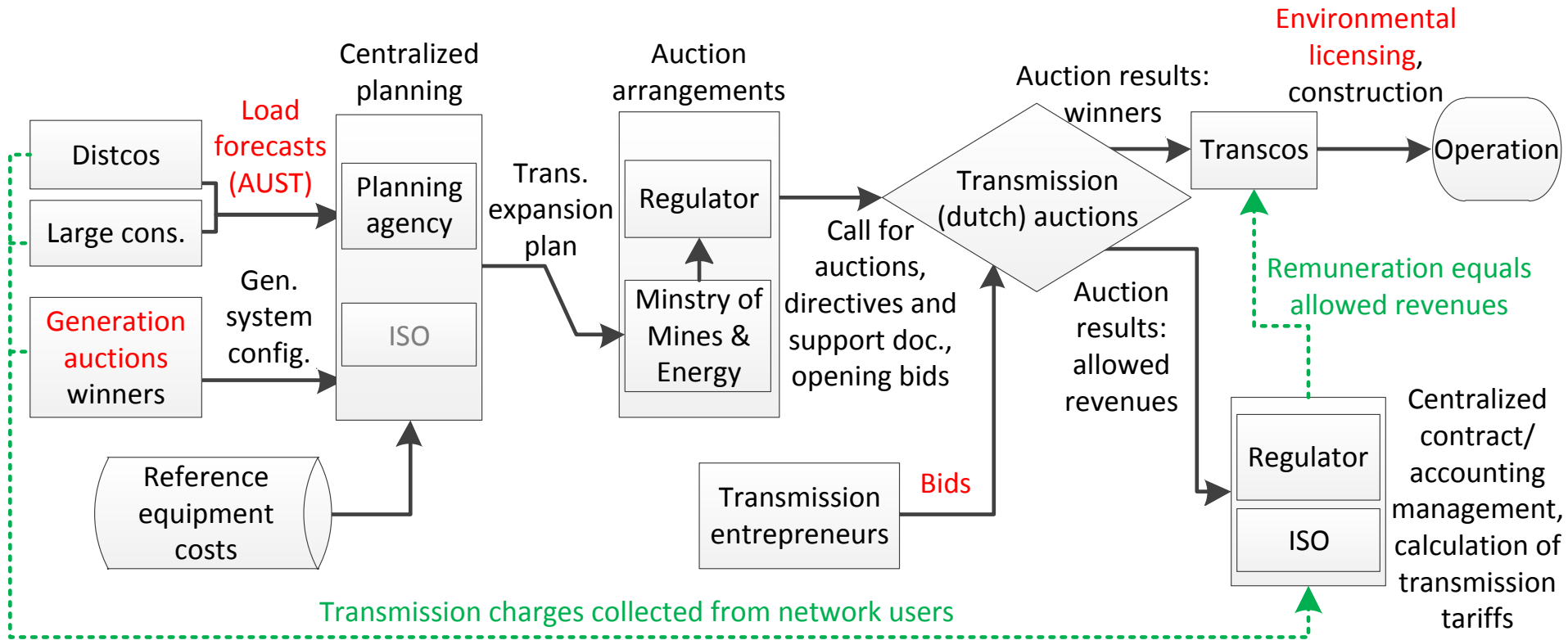
- Sept 1994 -3 generators proposed 4th Line
- Public hearing Feb 1995 - 50% vote against (surprise and concern)
- May 1996 revised proposal – accepted
- Finally, 4th Line was not economic

- 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

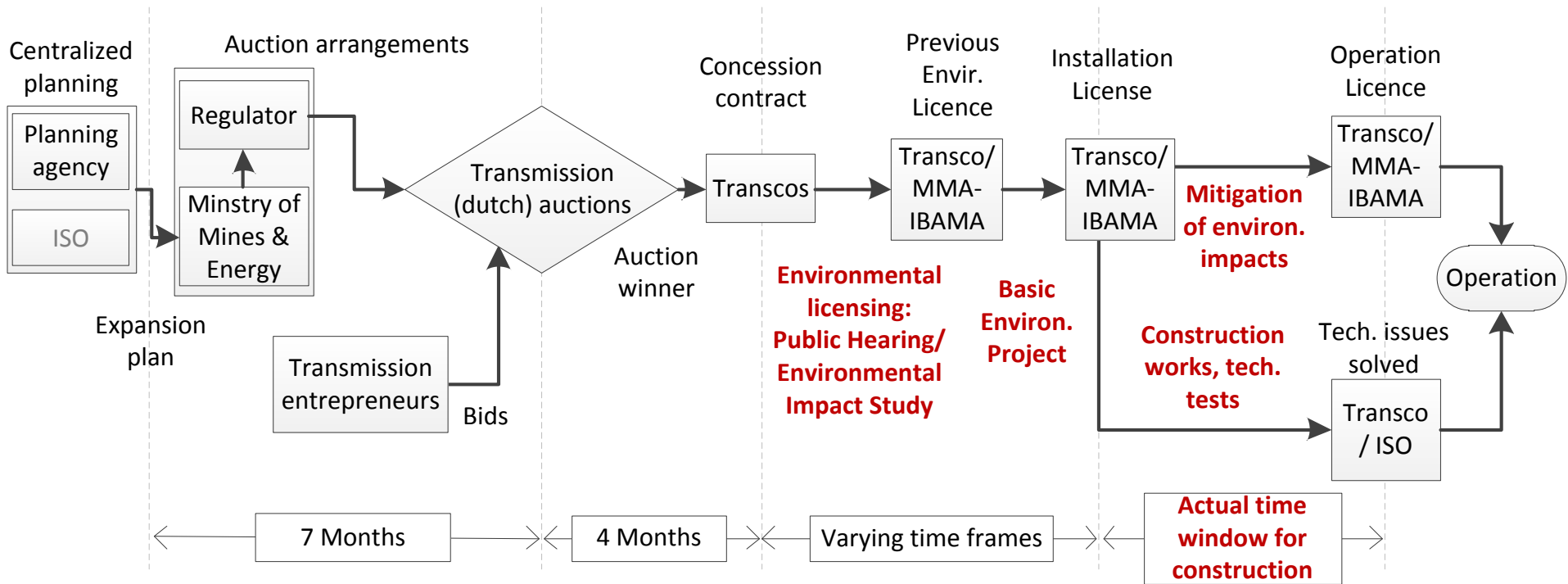
Public contest method worked well

- 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



Transmission expansion in 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

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