Pontificia Universidad Católica de Chile
Departamento de Ingeniería Eléctrica

Benchmark Regulation and Efficiency of Electricity Distribution

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Bundesnetzagentur Conference
Bonn, 25-26 April 2006

Objective

Share the experience of Latin American countries that, from 1982 onwards, reformed their electricity power sectors to establish conditions of economic efficiency and attract private investment, replacing central planning and control by market oriented approaches.

Competition was introduced in generation and "pseudo competition" in transmission and distribution.

Share the characteristics of benchmark yard stick regulation for distribution, with analytical cost models, model company and model network concepts, used in Chile, Argentina, Peru and others.

The importance of efficiency in distribution

Regulating the monopoly

The distribution activity- costs to consider

Analytical models

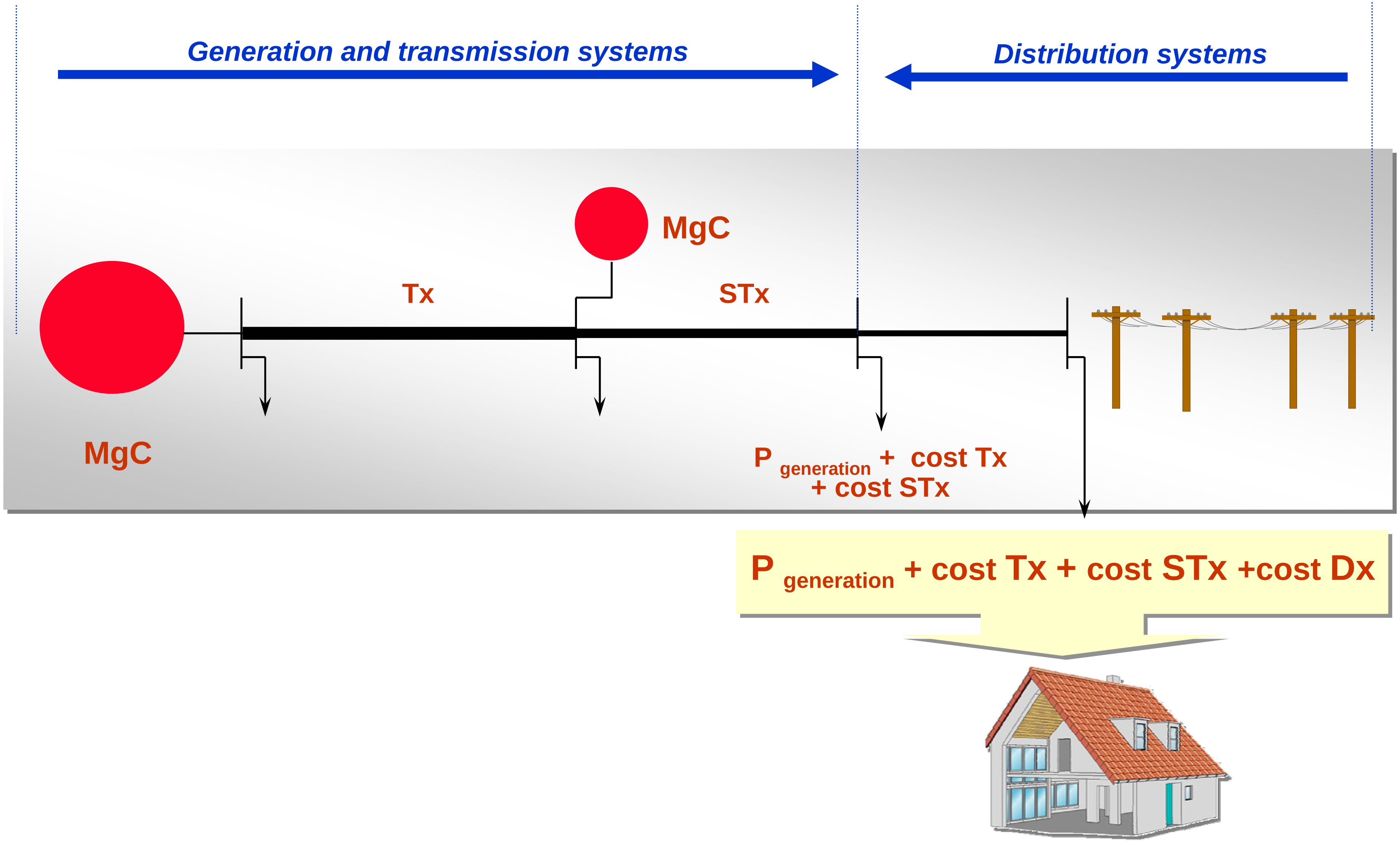
The building of an efficient company

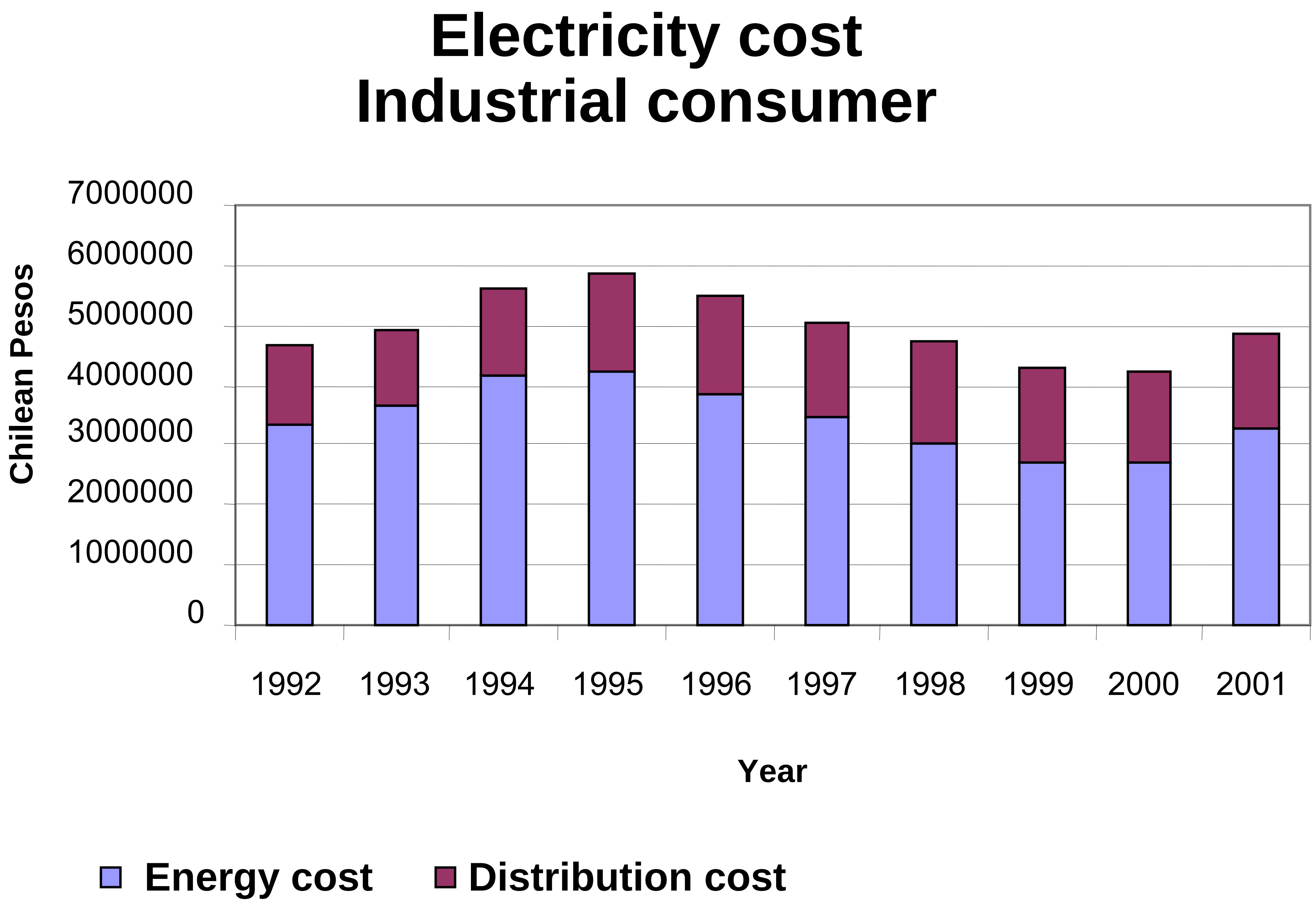
Results of incentive regulation

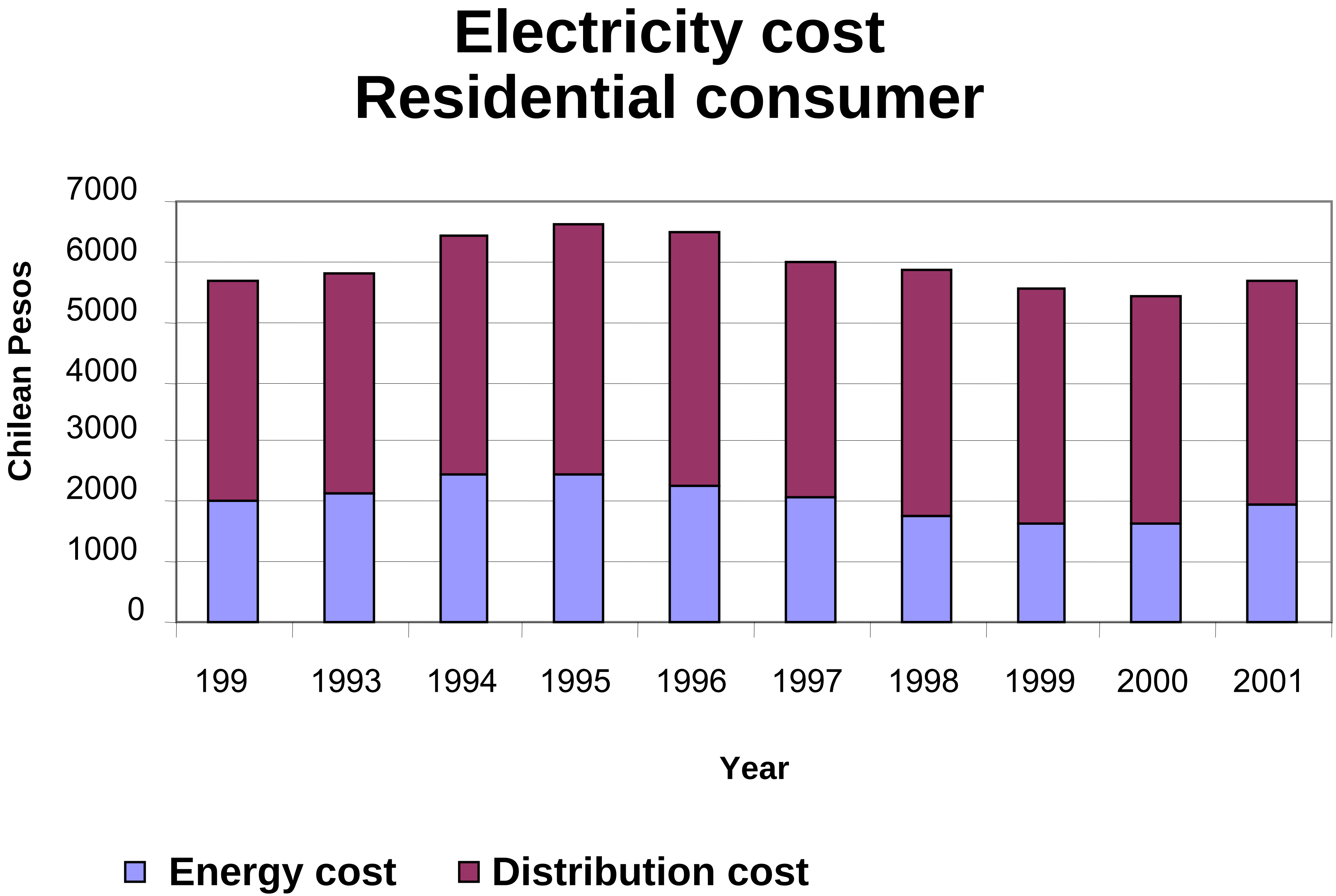
Projections into the future (DEA, SFA, etc.)

Other elements of regulation

The building of the price for the final consumer




Electricity cost
Industrial consumer
7000000
6000000
5000000
4000000
3000000
2000000
1000000
0
Chilean Pesos
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
Year
Energy cost
Distribution cost



Electricity cost
Residential consumer
Chilean Pesos
7000
6000
5000
4000
3000
2000
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199
1993
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1997
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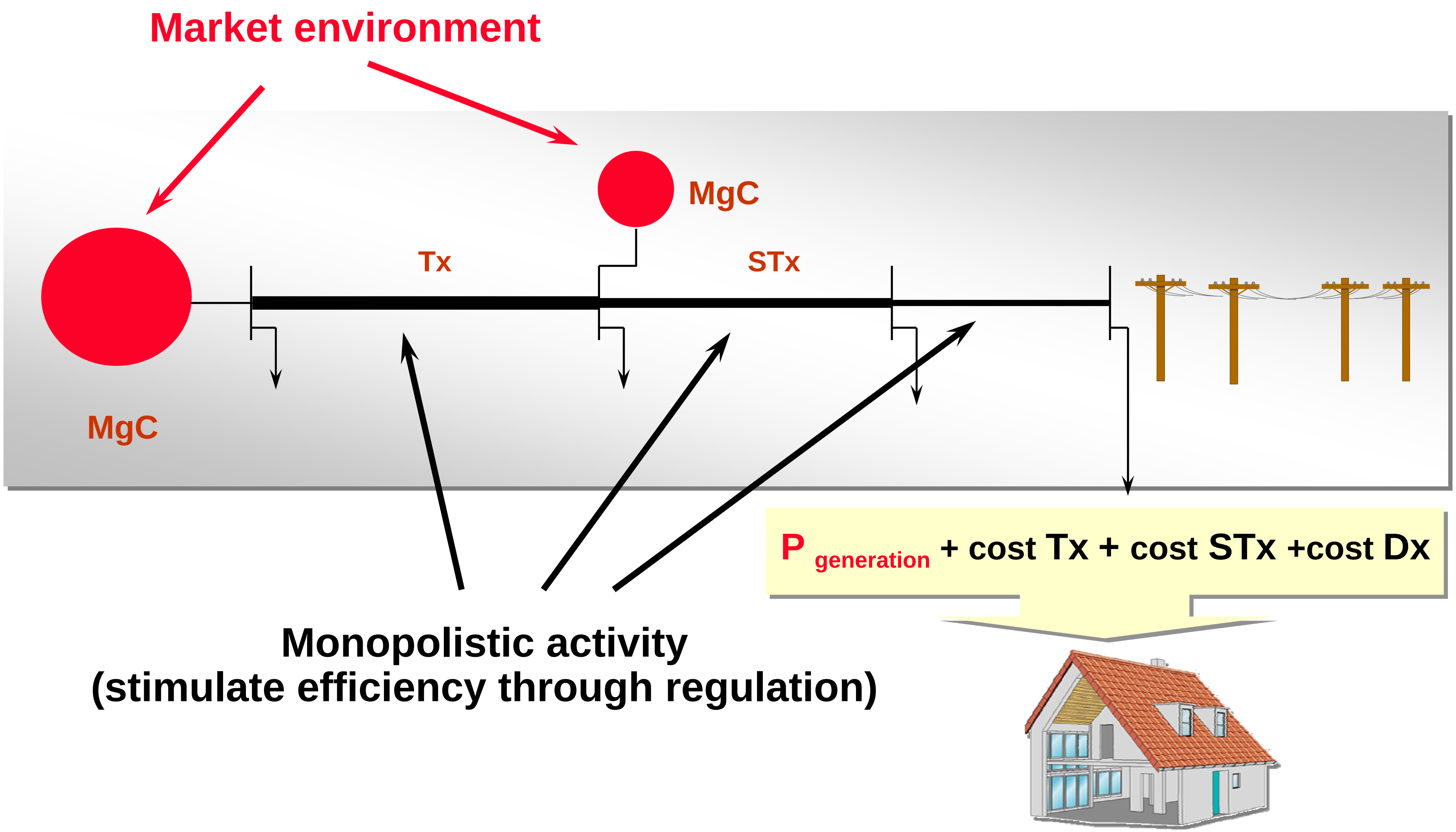
1999
2000
2001
Year
Energy cost
Distribution cost

Market reforms: benefit final consumer



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Price regulation objectives for monopoly

Strategic objectives

- -avoid loses of monopoly prices
- -avoid individual tariff considerations
- -provide
  - -economic efficiency signals for operation and investment
  - -flexibility and stability
  - -adequate response to market changes
  - -symmetry of risks and opportunities for the regulated agent

Prices must be fixed considering

- -cost of service provision
  - -reflect to the consumer the supply cost structure
- -adequate return to investment capital
- -incentives for cost reduction

Distribution monopoly regulation

Requirements

-concession required to run the business
-public service activity
-obligation to serve
-open access to wires
-quality of service regulated

Rights

-concession granted for the right to use public roads and private grounds with compensation
-realistic price regulation considering restrictions
-adequate return to investment capital, if efficient
-higher efficiency rewarded

Regulatory Models

All models to regulate industrial monopolies consider **fixing initial prices** and **adjusting them with time**.

$$P_o \cdot f(P'_t) + Z_t = P_t$$

- P_o: *Initial Price*
- $f(P'_t)$: *Annual adjustment factor*
- Z_t: *Adjustment*
- P_t: *Price in year t*

Regulatory Models

Fixing initial prices

From "*what are the costs?*" to "*what they should/could be?*"

Based on real costs, standardised ones, efficient ones?

Adjustment with time

Regulatory models adjust prices on a yearly bases, given parameter changes or incentive needs

Based on inflation, efficiency increases?

Regulatory Models

Cost Plus (Cost based) Regulation

recognize real costs and determine required rent, no incentives to reduce costs

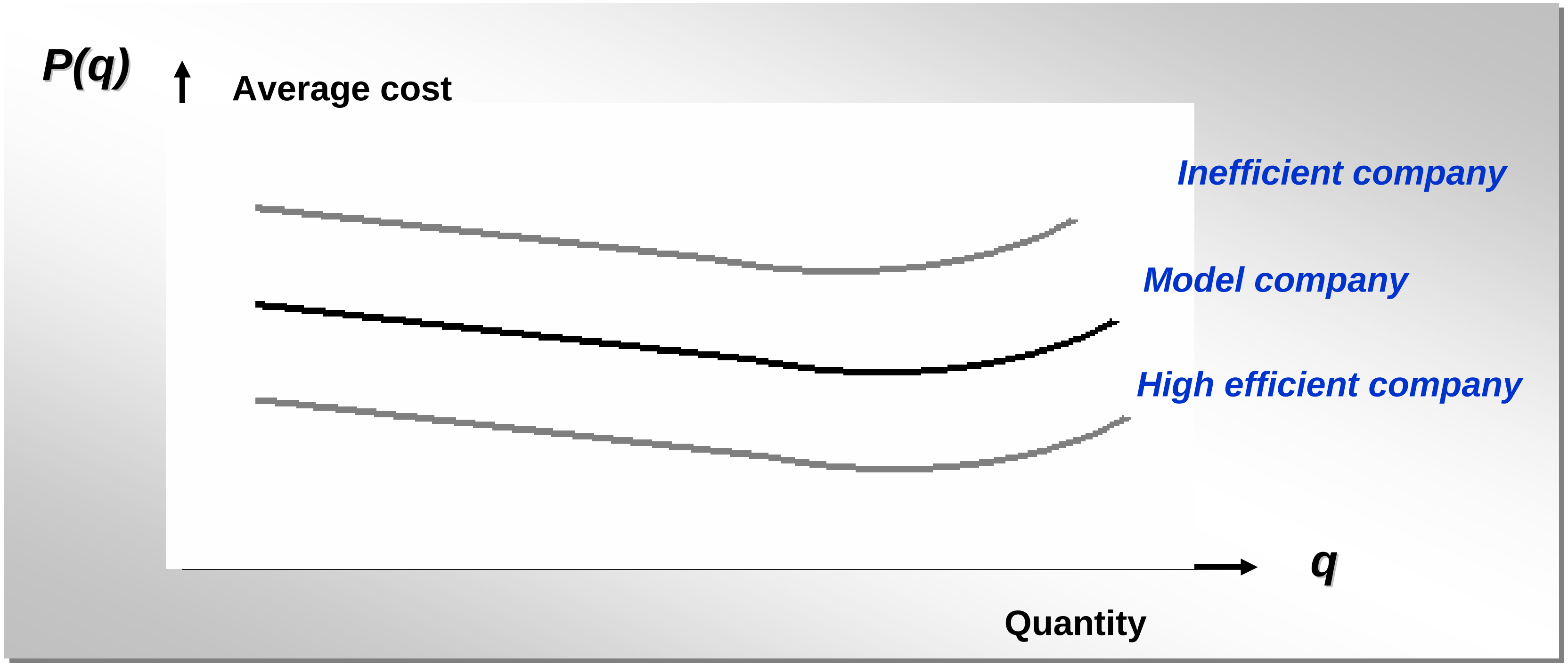
Incentive Regulation - Price Cap

bridge between traditional regulation and deregulation – costs fixed and reduced over time (productivity index RPI-X)

Model Company or Yardstick Competition

possibility to compare costs of different similar companies- introduction of concept of a model company

Model Company or Yardstick Competition



- ❑ Comparison of different companies achieved through identifying different “distribution areas”
- ❑ Models determined for each area, tariffs different for each area

Challenges

-definition of “efficient” investment and administration

-manage information deficiencies

-regulator independent from monopoly pressure (avoid capture)

-need to consider reliability and quality of supply

Risks

-conflictive interests between regulator and monopoly

-regulator manipulating model company with other objectives

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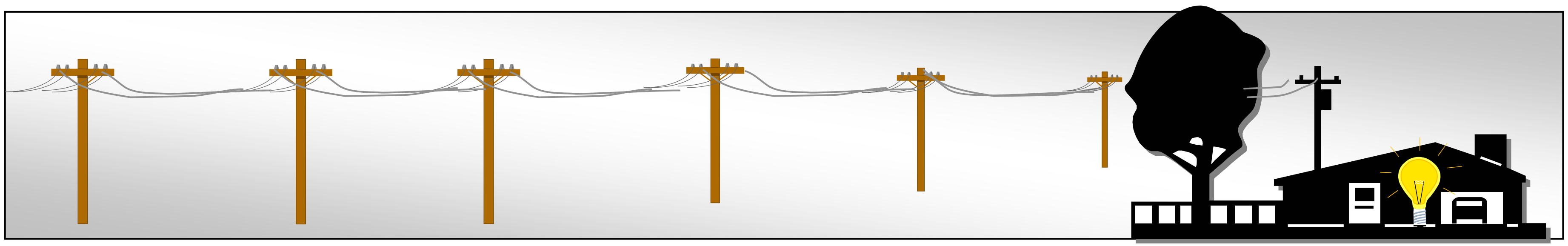
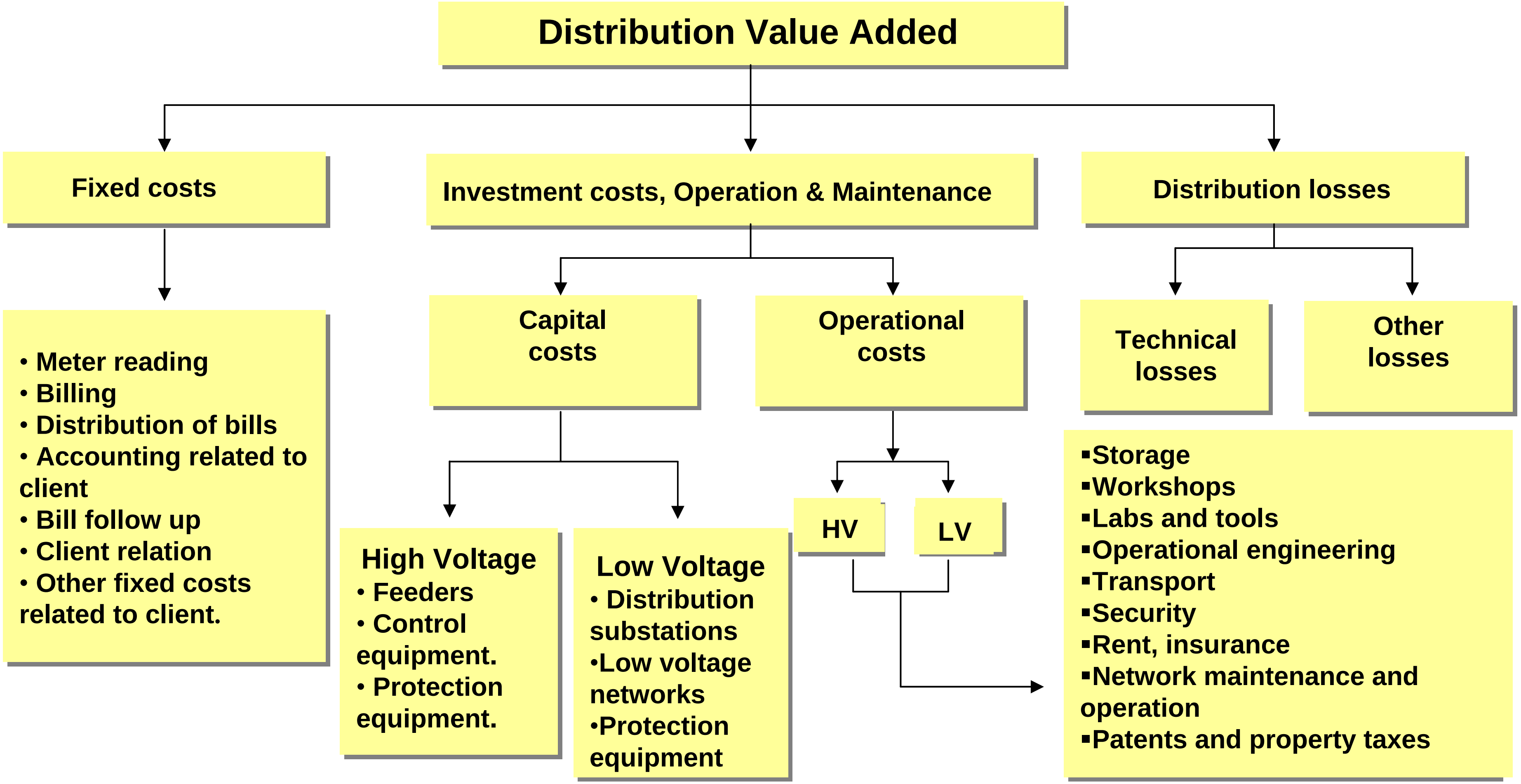
Process of electricity distribution

Investment planning	Network construction	System operations	System maintenance	Business management
• Identify new system needs. • Develop plans to satisfy need. • Facilitate plans and budgets. •Assess large projects.	• Build lines, substations, low voltage networks.	• Connections & disconnections •Follow up and control of system operations •Correct damages & incidents.	• Maintenance of lines, substations and low voltage networks. • Maintenance of protection equipment.	• Measurement, meter reading •Billing •Contracts •Solution management.



Cost components in added distribution value



Characteristics of distribution costs

Cost of distribution dictated by capacity requirements (demand defines network dimensioning, thus defines investment and operation)

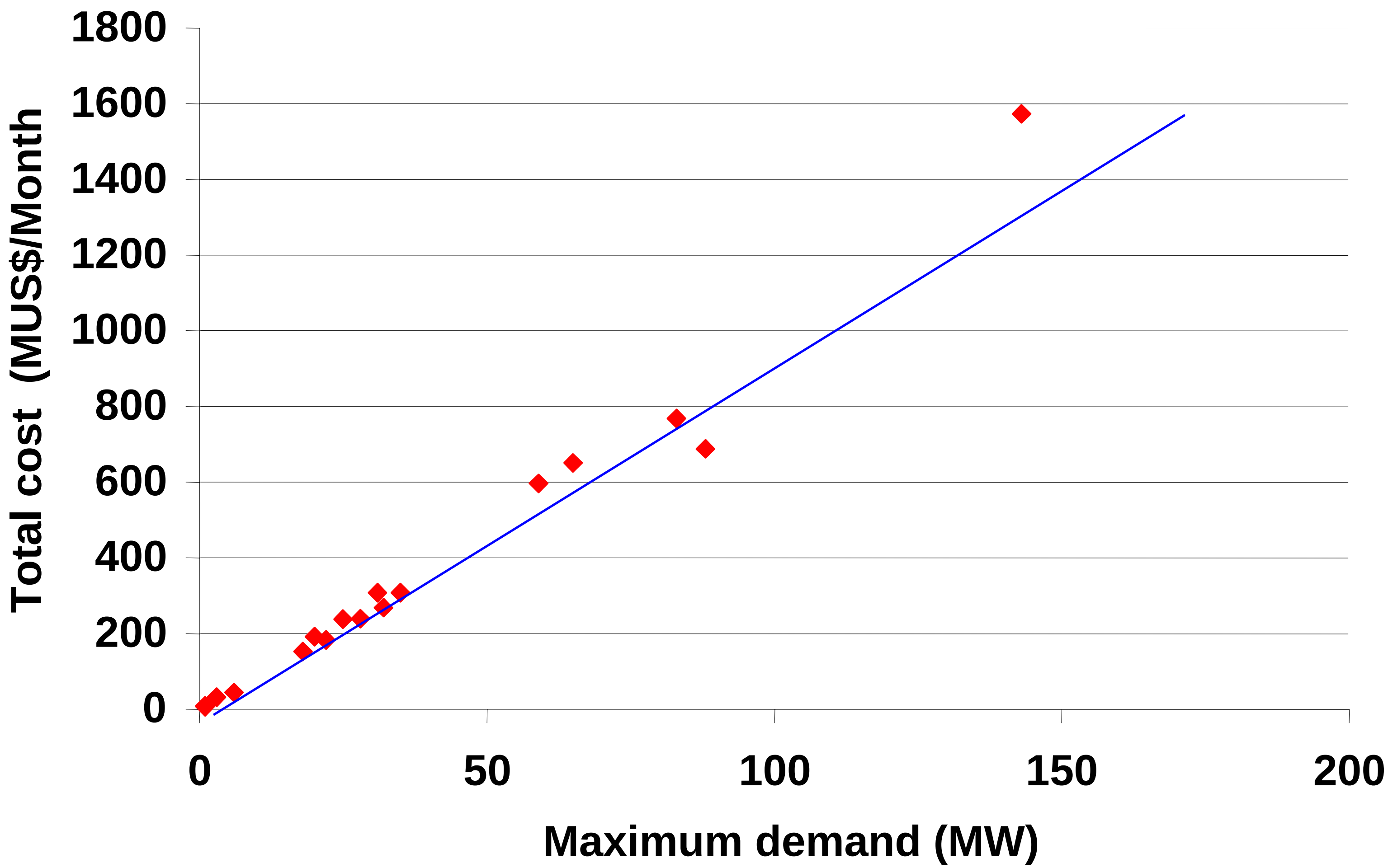
Energy only important given network losses

Important economies of scope (the higher the load density, the lower the unit costs)

Marginal cost of distribution equal to average costs (except for high density)

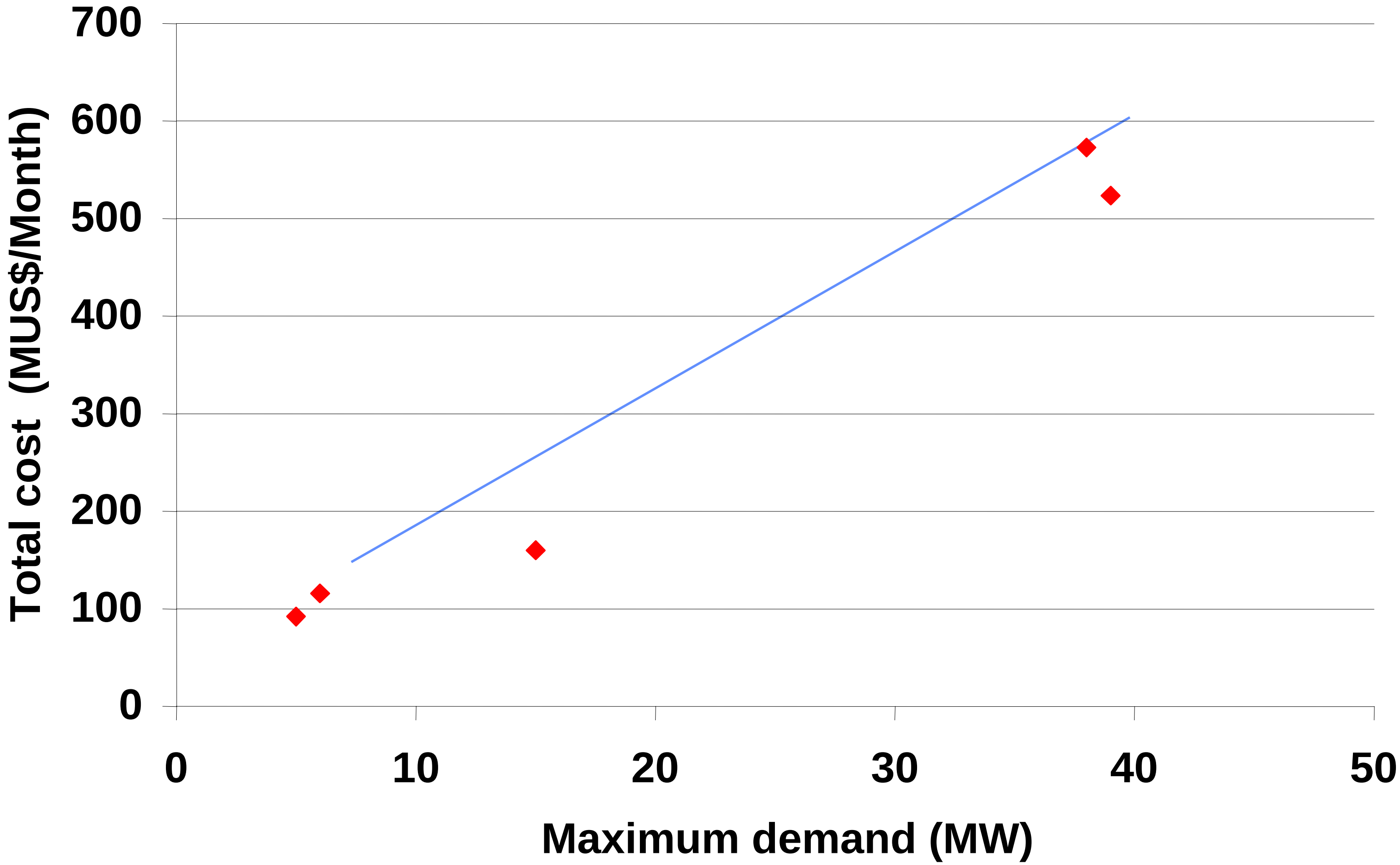
Distribution characteristics

Total monthly costs **semi urban area**, Chile, 1988
Average value 10,2 US$/kW/month



Distribution characteristics

Total monthly cost **rural area**, Chile, 1988)
Average values 13,8 US$/kW/month



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Cost structure for distribution

$$Cost = \frac{Investment \quad annuity + Operation + Losses}{kW_{HV} + kW_{LV}}$$

Replacement cost concept for investment.

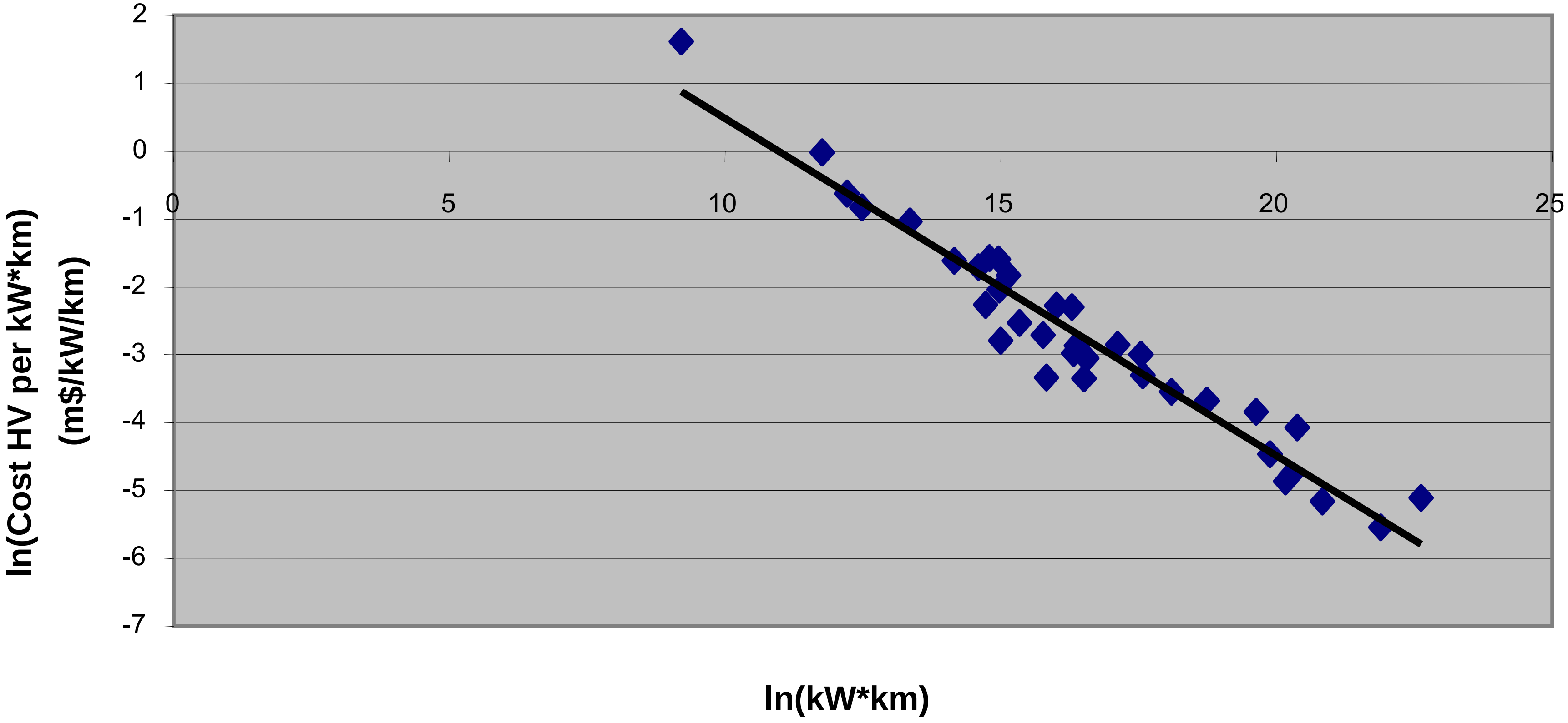
Investment annuity considering useful life of installations and given return rate.

Econometric models are built to represent the industry costs, with a log-log regression between the average cost per km*kW and the km*kW, for high voltage and low voltage.

Following examples represent Chilean distribution industry.

Distribution characteristics

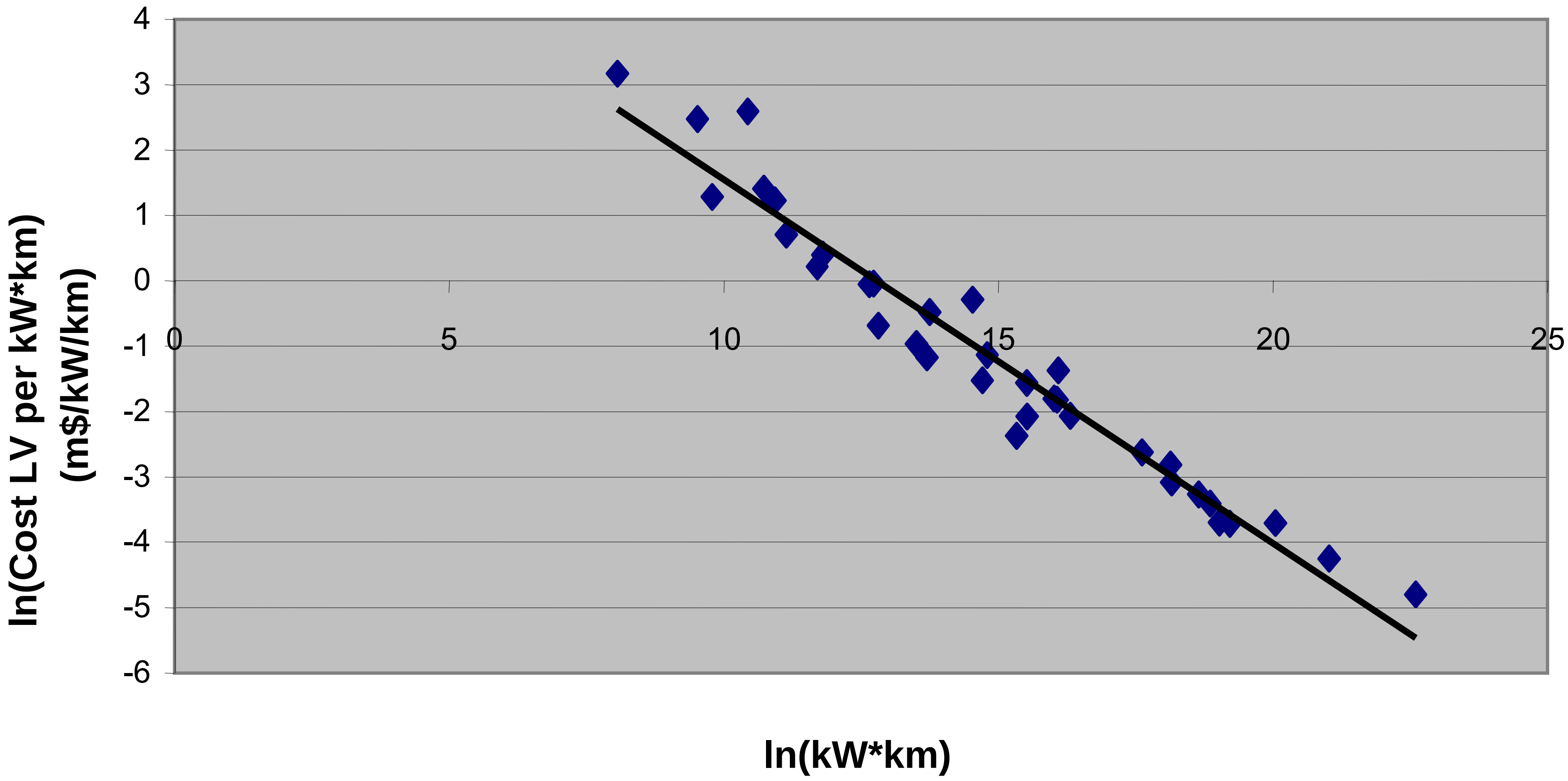
Relation between unit costs HV and the product kmHV*(kWHV+kWLV)



$$Cost_{HV} = \mathrm{km}_{\mathrm{HV}} \cdot \left(\mathrm{kW}_{\mathrm{HV}} + \mathrm{kW}_{\mathrm{LV}}\right) \cdot e^{\left(A \cdot \ln\left(km_{HV} \cdot \left(kW_{HV} + kW_{LV}\right)\right) + B\right)}$$

Distribution characteristics

Relation between unit cost LV and the product kmLV*kWLV



$$Cost_{LV} = \mathrm{km}_{\mathrm{LV}} \cdot \mathrm{kW}_{\mathrm{LV}} \cdot e^{\left(A \cdot \ln\left(km_{LV} \cdot kW_{LV}\right) + B\right)}$$

Código empresa	Nombre empresa	VNR AT (m$)	VNR BT (m$)	CExp AT (m$)	CExp BT (m$)
1	Emelari	5,153,988	7,801,464	1,190,883	1,419,617
2	Eliqsa	7,135,682	8,992,105	1,466,897	1,567,474
3	Elecda	14,863,113	19,105,397	2,271,316	2,875,336
4	Emelat	9,785,113	9,703,282	1,989,908	1,439,124
5	Emec	28,575,191	27,794,254	2,937,812	2,697,148
6	Chilquinta	38,583,871	56,391,652	5,672,466	10,634,949
7	Conafe	23,093,035	22,692,748	1,626,828	2,728,035
8	Emelca	534,186	423,750	107,957	49,527
9	Litoral	2,847,422	4,901,432	299,363	875,181
10	Chilectra	128,030,463	217,238,697	14,196,894	33,451,971
11	Río Maipo	19,502,398	23,618,141	3,526,467	4,333,649
12	Colina	537,190	1,031,961	100,731	243,856

Investment (VNR) and operation cost (Cexp) for 12 of the 39 companies considered

Código empresa	Nombre empresa	LRATET o km AT eq trif (km)	LRBTET o km BT eq trif (km)	kW AT+BT (kW)	kW BT (kW)
1	Emelari	291.6	457.2	47,789.8	23,360.2
2	Eliqsa	496.7	432.0	85,611.9	41,570.2
3	Elecda	545.6	859.3	148,275.5	90,435.1
4	Emelat	935.0	564.4	126,105.1	44,562.3
5	Emec	3,170.7	2,350.3	192,306.1	85,893.1
6	Chilquinta	2,450.5	3,486.3	362,610.8	183,866.0
7	Conafe	1,223.3	1,358.7	181,134.0	98,980.6
8	Emelca	65.5	47.2	2,459.5	1,894.8
9	Litoral	259.3	461.4	18,163.5	15,859.7
10	Chilectra	4,323.3	7,898.7	2,358,651.3	1,466,327.4
11	Rio Maipo	1,496.0	1,644.7	324,569.5	166,370.5
12	Colina	54.0	109.4	9,786.2	6,610.9
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Physical parameters: length of HV and LV networks, kW demand HV and LV

Structure of yardstick competition

Industry segmentation

-companies are grouped according to similar distribution costs, considering a maximum deviation

-segments are identified

Reference company is chosen for each segment

-cost close to the group average

-representation coverage

-existence of previous studies

Efficiency distribution costs determined for each segment

-global industry check up

Tariffs set every four years

-indexation

2004 Chilean study

Segments and model company

Area 1: **Chilectra**

Area 2: Río Maipo, Emelat, **CGE** , Luzandes, Puente Alto, Eliqsa, Elecda, Conafe, Coop. Curicó.

Area 3: Chilquinta, Emelari, Edelmag, **Emec**, Emelectric, Energía de Casablanca, Saesa.

Area 4: Elecoop, **Colina**, Edelaysen.

Area 5: Til Til, **Luzlinares**, Emetal, Litoral, Frontel, Luzosorno

Area 6: Emelca, Luzparral, Socoepa, Codiner, Coopelan, **Copelec**, Coelcha, Cooprel.

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Building the efficient company

Efficient network

- -Low voltage network design
- -Distribution transformer sizing
- -High voltage network design

Efficient infrastructure (buildings and facilities)

Efficient management

Energy and capacity balances

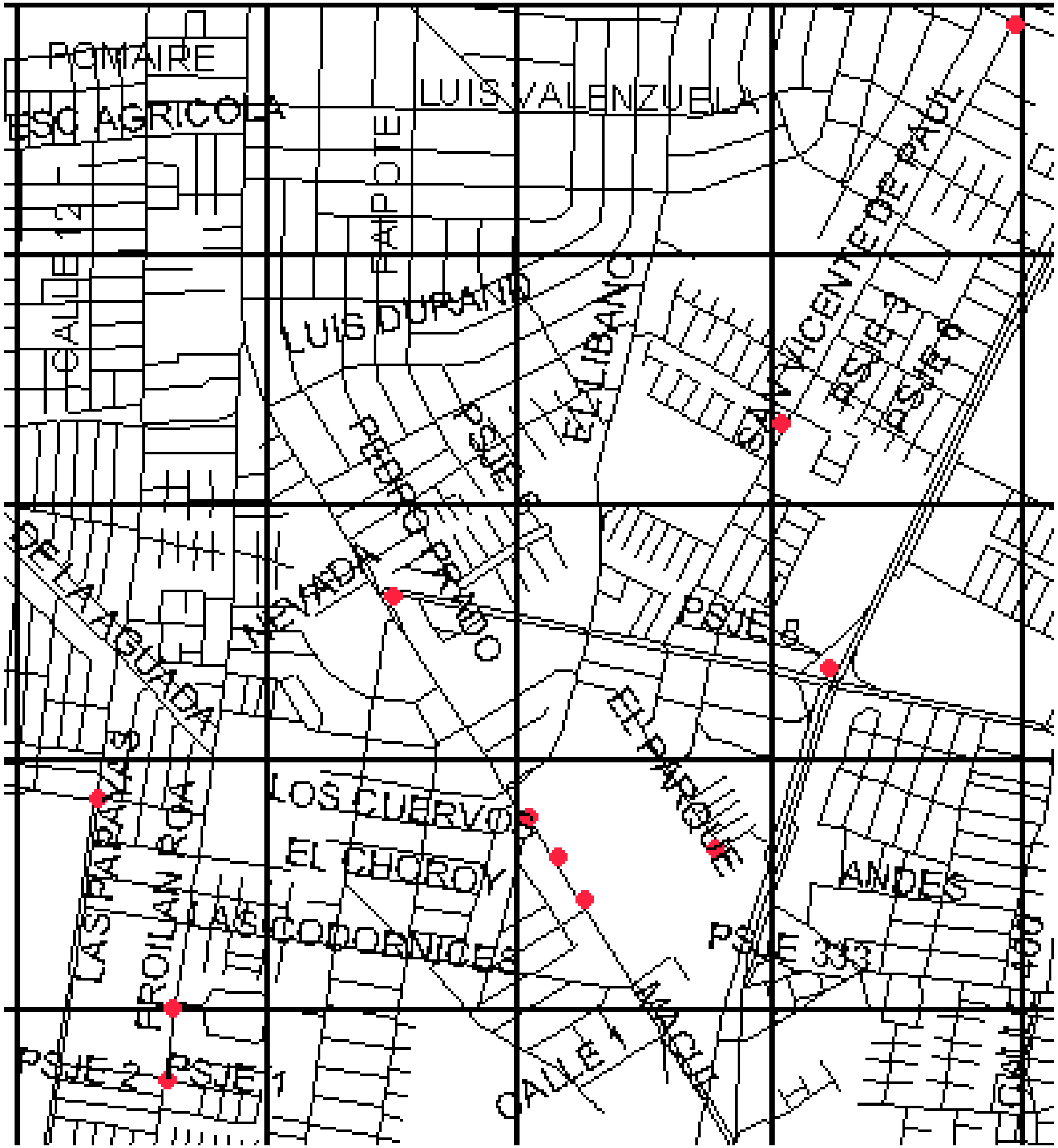
Loss calculations

Use of geographical information - GIS based

LOW VOLTAGE NETWORK DESIGN

Based on identification of families of cells, electric project for sample ones, extrapolation to universe

500*500 meter cells



Conductor and transformer selection

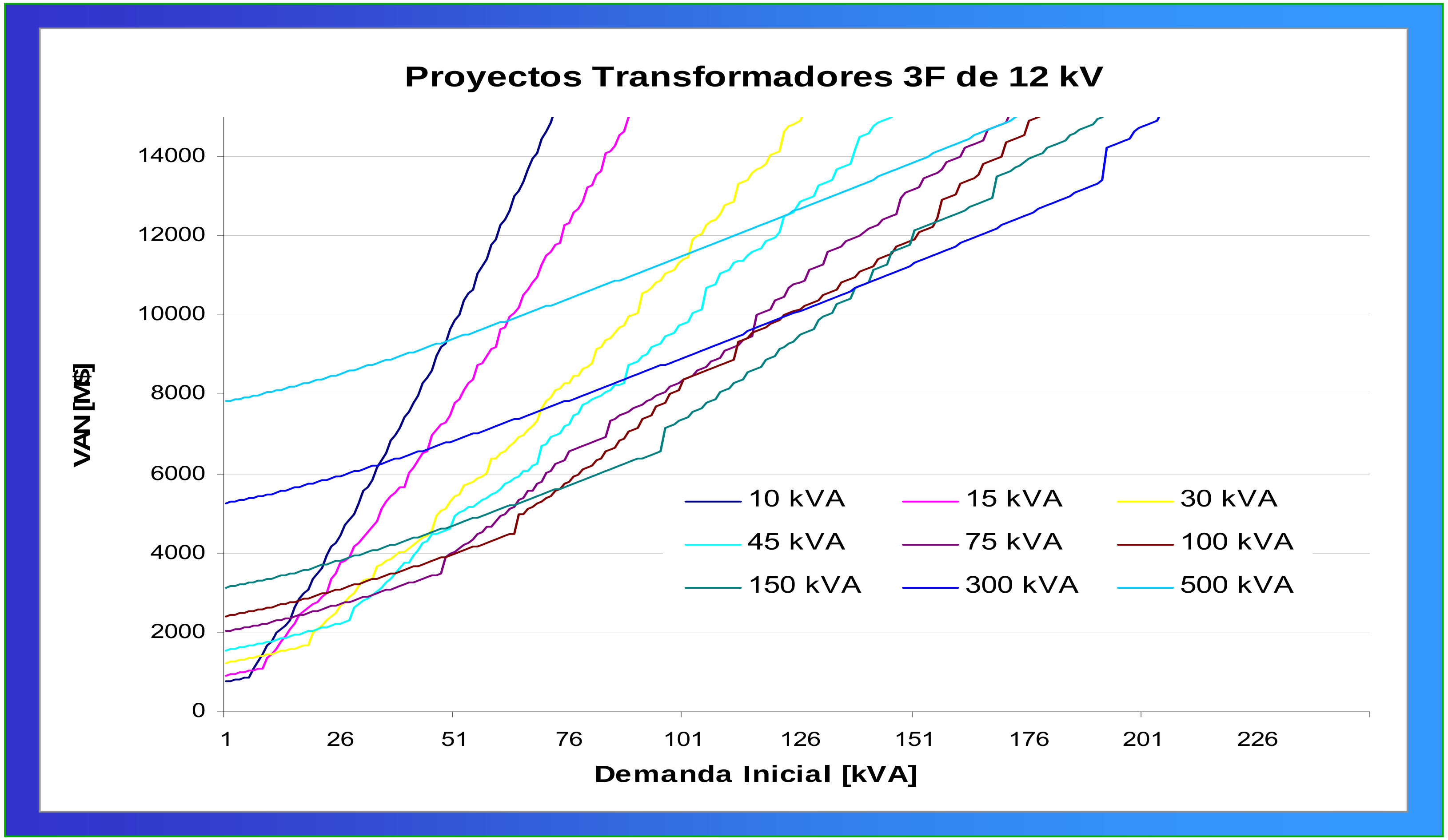
Objective function

-minimize present value of investment, losses and depreciation.

Parameters (2004)

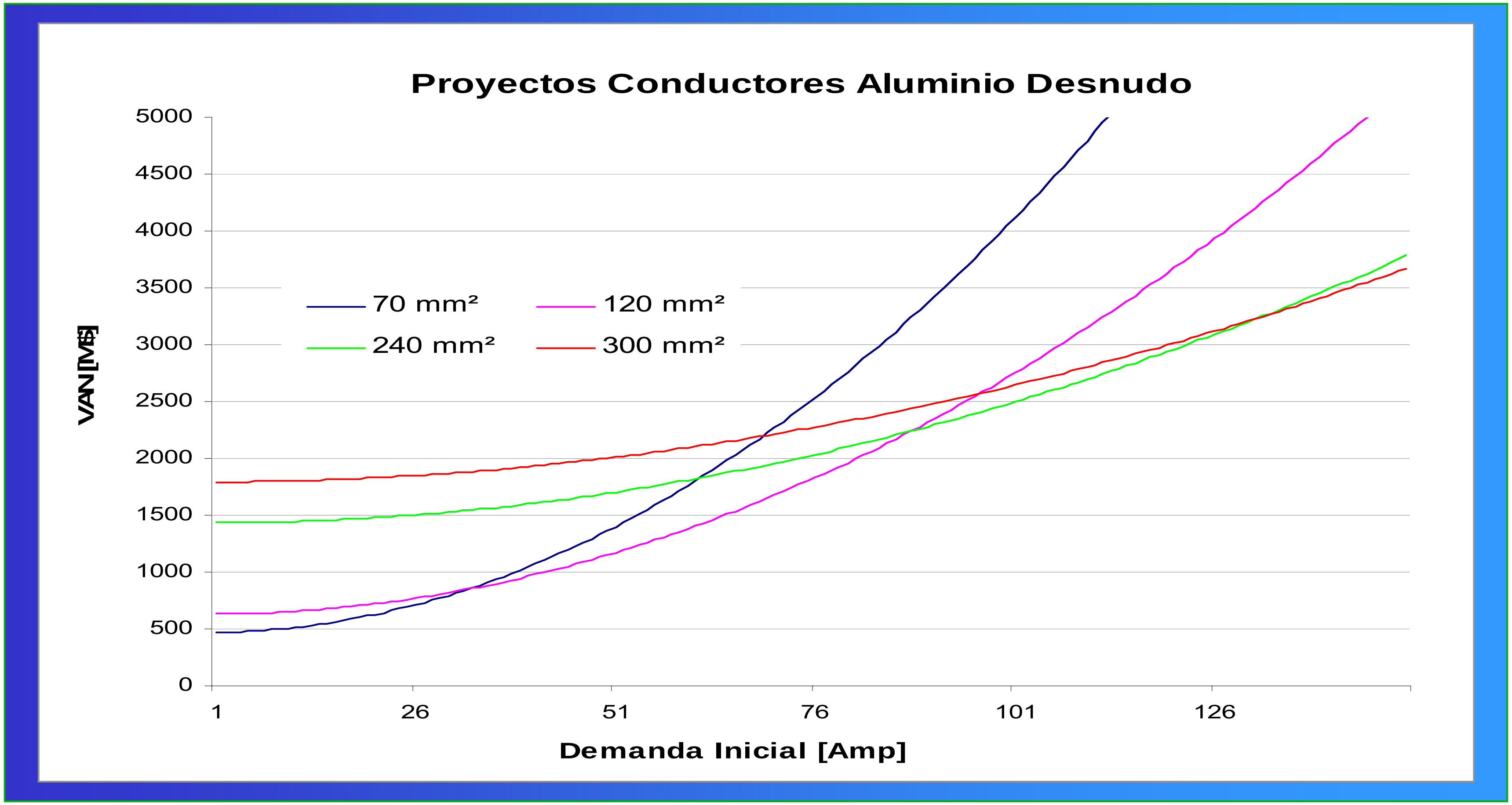
	Value	Unit	Description
N	15	Years	Study horizon
Td	10	%	Return rate
Tc	0 a 3	%	Demand growth rate
ρ_E	18,55	$/kWh	Energy price
ρ_P	5.523,36	$/kW	Capacity price

Transformer selection



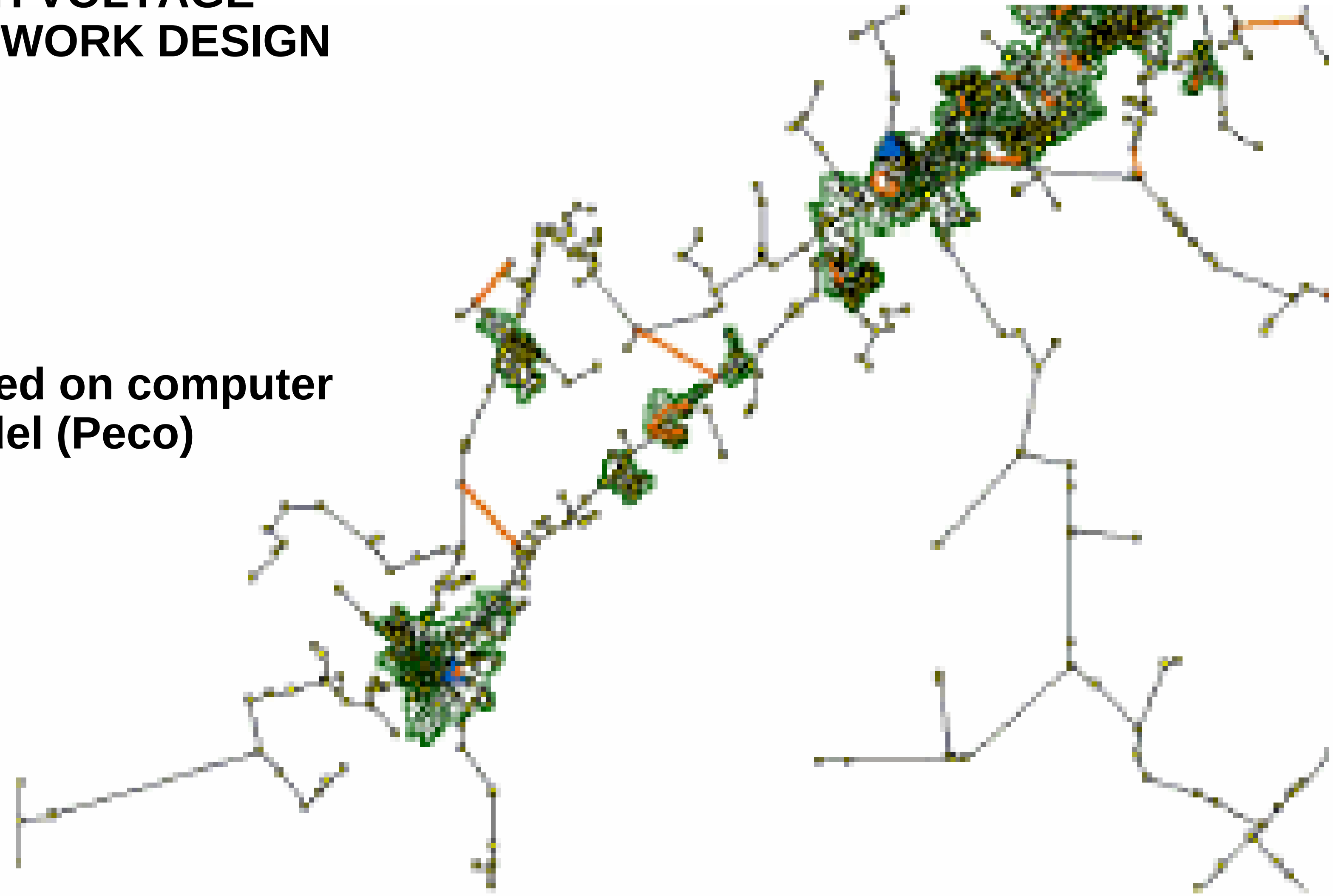
$$VAN^{i} = \sum_{k=0}^{N} \frac{INV_{k}^{i} + CPT_{k+1}^{i} \cdot (1-\tau) - DEP_{k+1}^{i} \cdot \tau}{(1+Td)^{k}}$$

Conductor selection



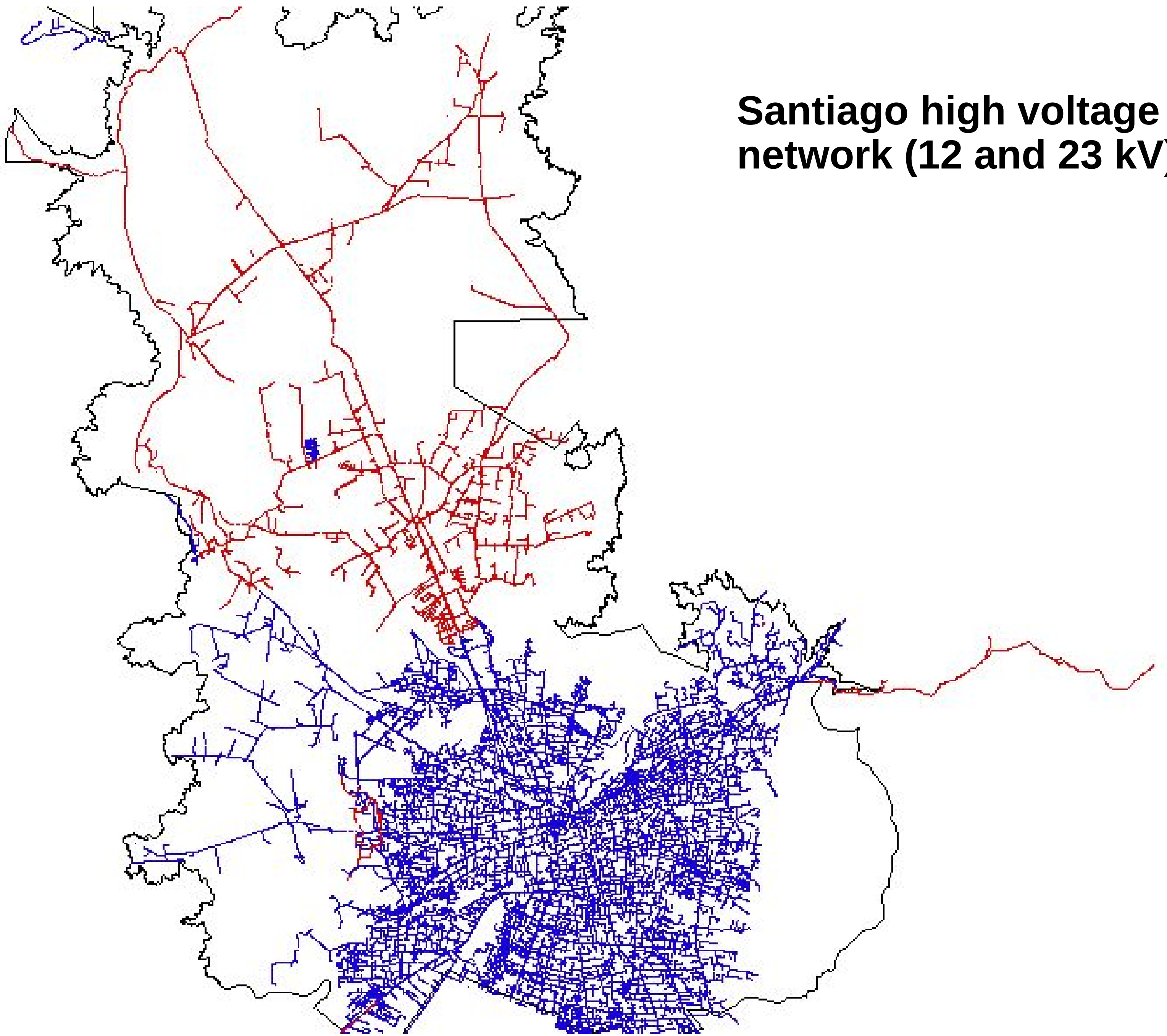
$$VAN^{i} = \sum_{k=0}^{N} \frac{INV_{k}^{i} + CPT_{k+1}^{i} \cdot (1-\tau) - DEP_{k+1}^{i} \cdot \tau}{(1+Td)^{k}}$$

HIGH VOLTAGE NETWORK DESIGN



Based on computer model (Peco)

Santiago high voltage network (12 and 23 kV)



Summary of High Voltage distribution per company

Items		Unit	Quantity	Value M$
1.- AÉRIAL NETWORK				
	1.1 Km network	km		
	1.2 Poles	c/u		
	1.3 Structures	c/u		
	1.4 Electric equipment	c/u		
	1.5 Ground connections	c/u		
	1.6 Others	c/u		
Total Aerial				
2.- UNDERGROUND NETWORK				
	2.1 Km network	km		
	2.2 Vaults	c/u		
	2.3 Canals	c/u		
	2.4 Electric equipment	c/u		
	2.5 Ground connections	c/u		
	2.6 Others	c/u		
Total Underground				
Total Company				

Quality of service requirements

Interruption indexes	Urban	Rural
Interruption average frequency per transformer (FMIT)	5,0 times a year	7,0 times a year
Interruption average frequency per kVA, (FMTK)	3,5 times a year	5,0 times a year
Total interruption time per transformer, (TTIT)	22 hours a year	28 hours a year
Total interruption time per kVA, (TTIK)	13 hours a year	18 hours a year

Penalties
Compensations to consumers based on value of non served energy

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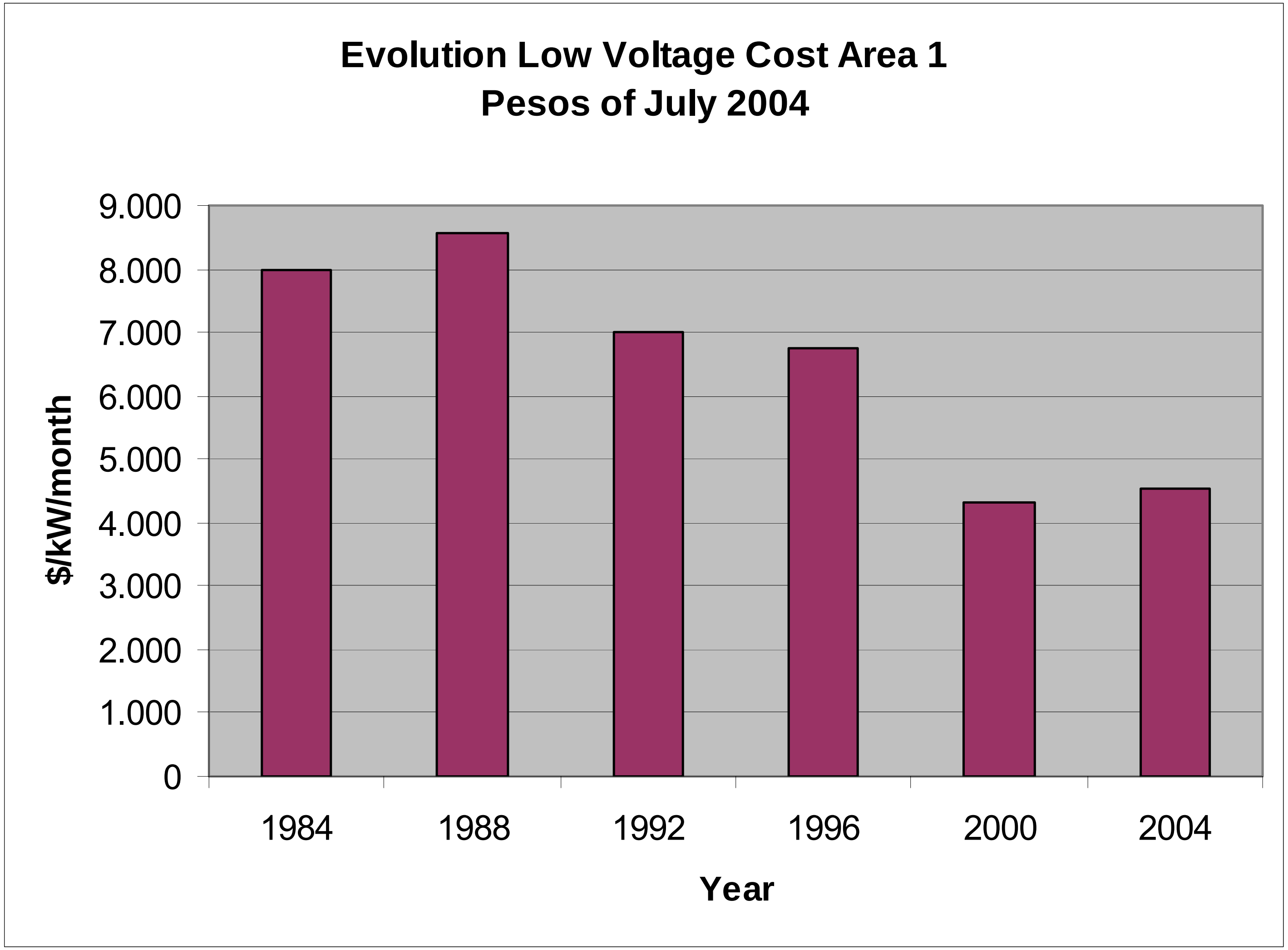
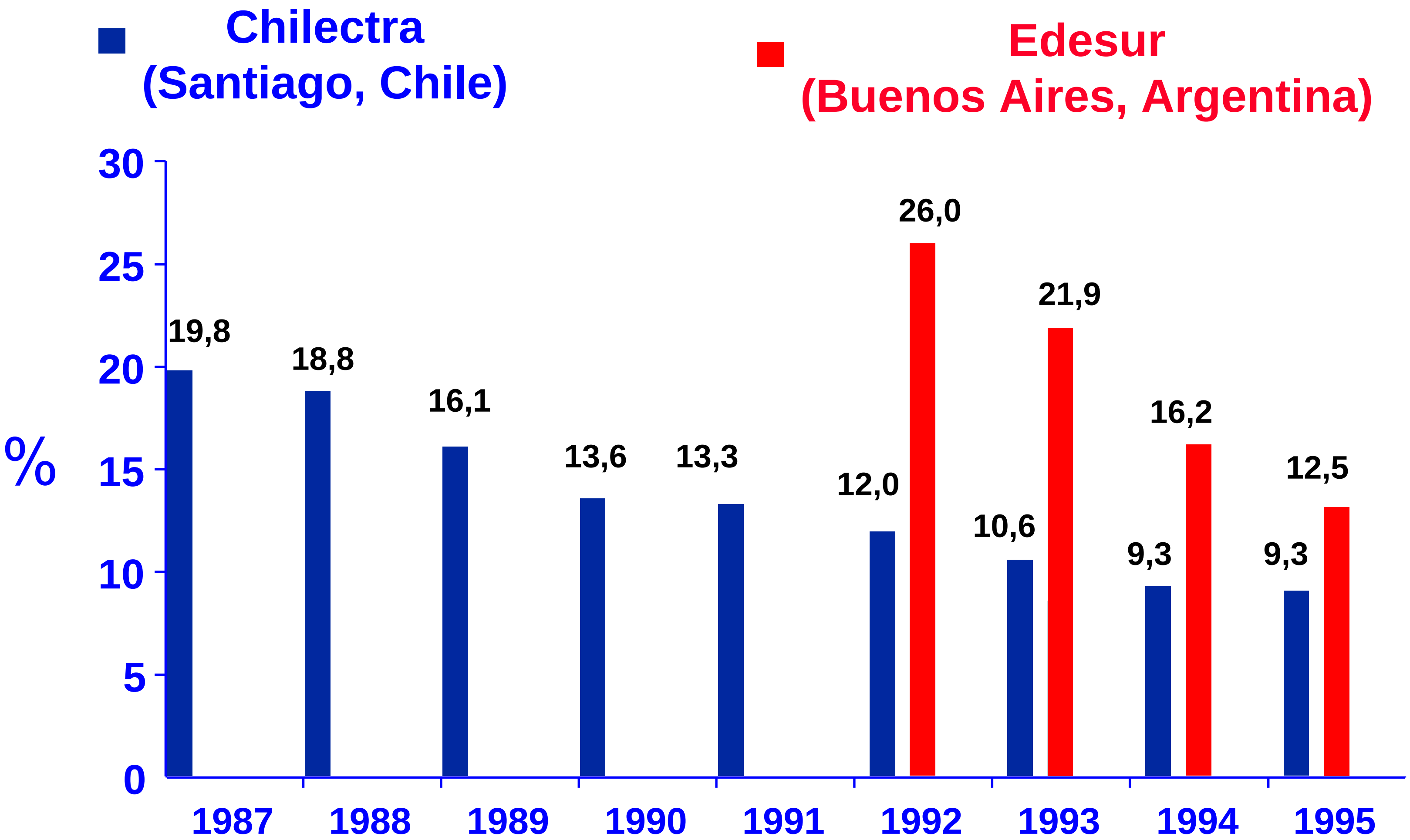
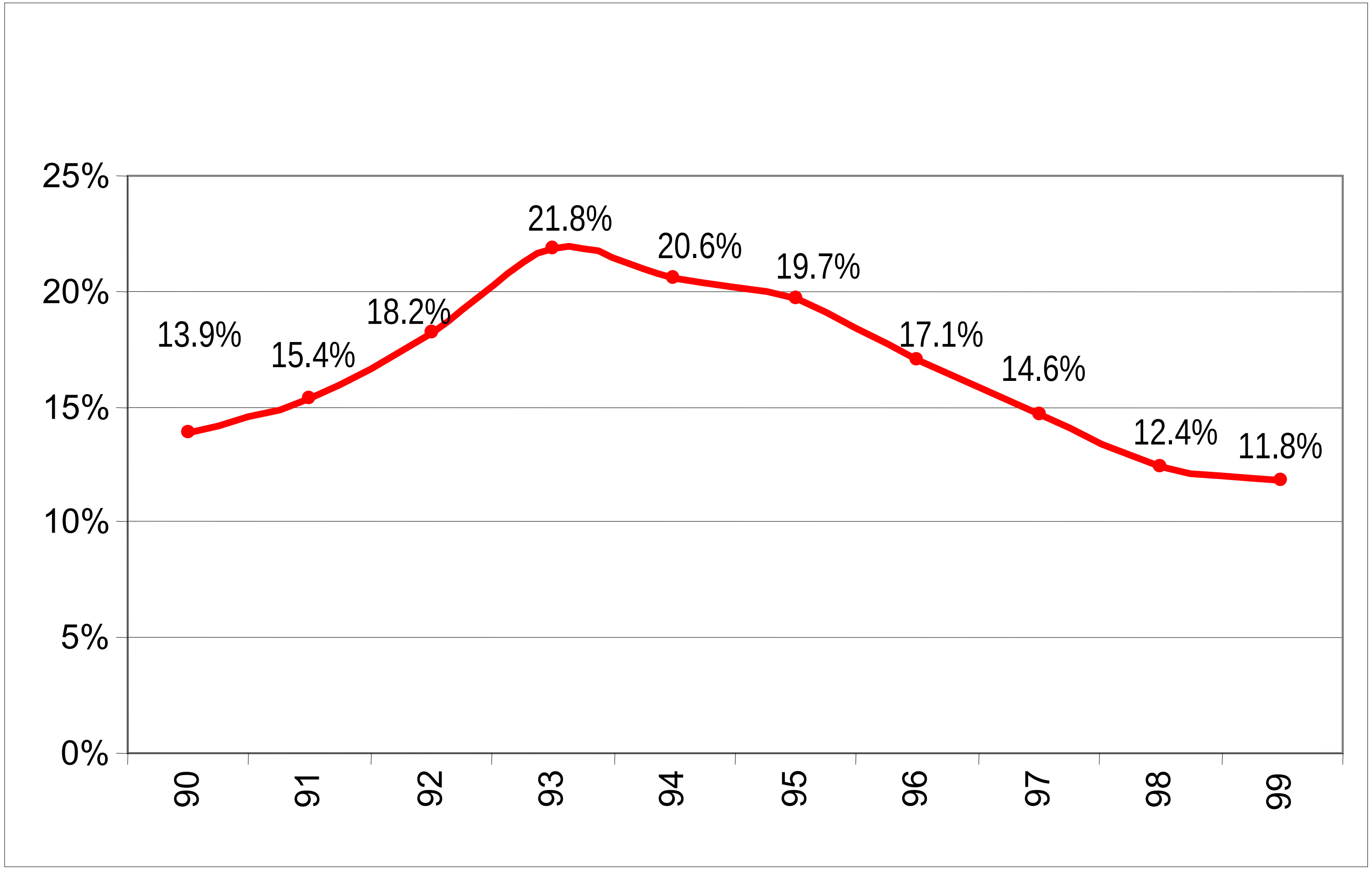
Cost reductions (Chile)



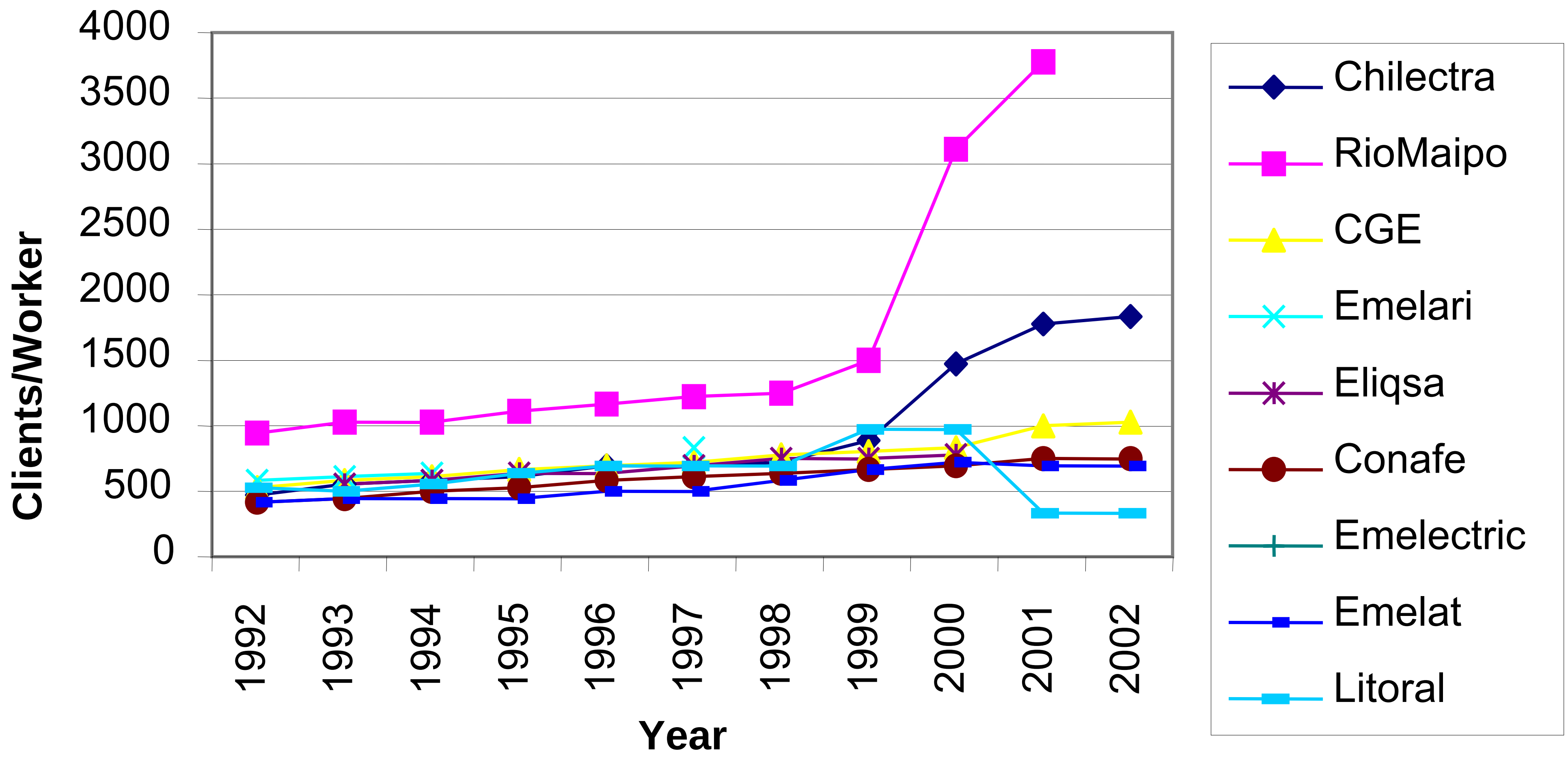
Loss reductions – technical and non technical



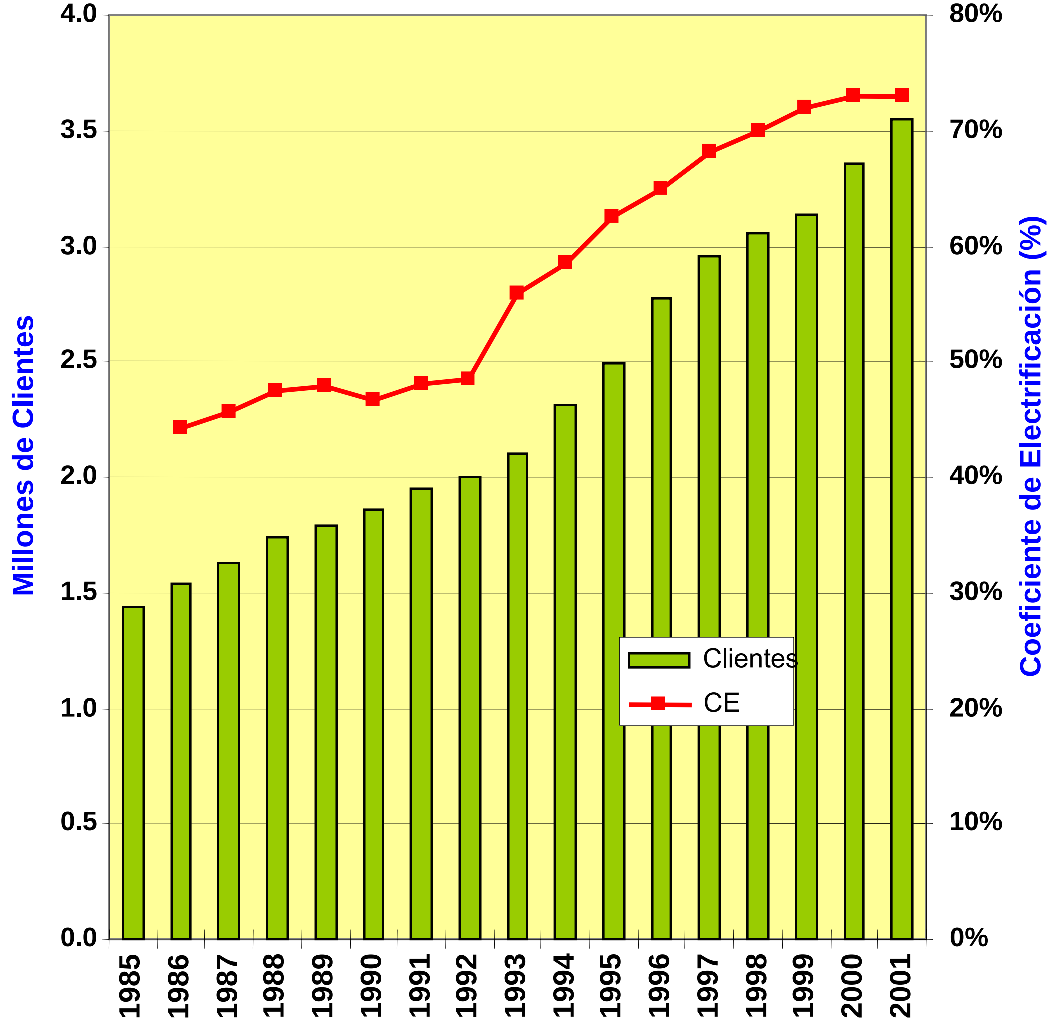
Loss reductions (Peru)



Clients per worker (Chile)



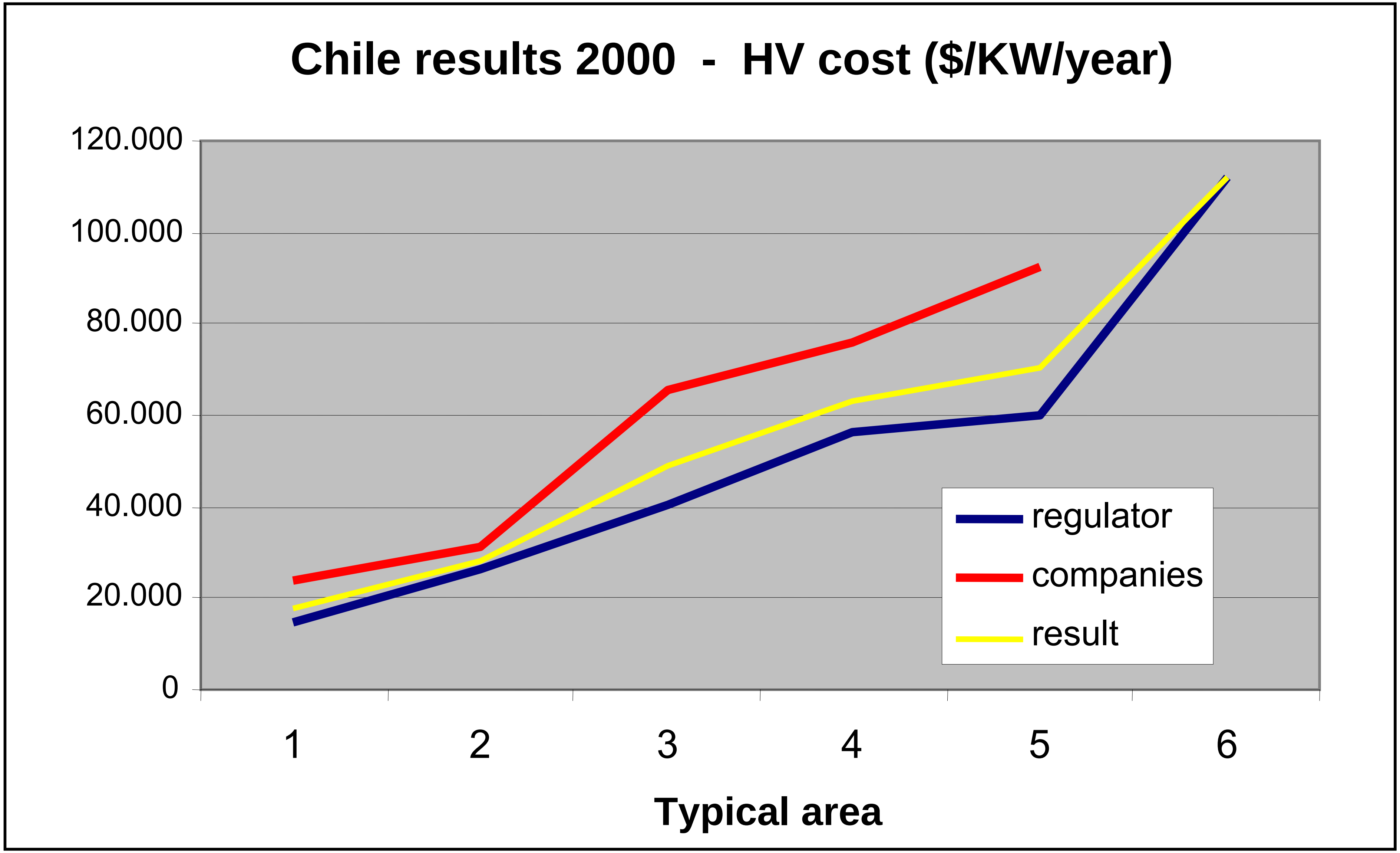
Supply coverage (Peru)



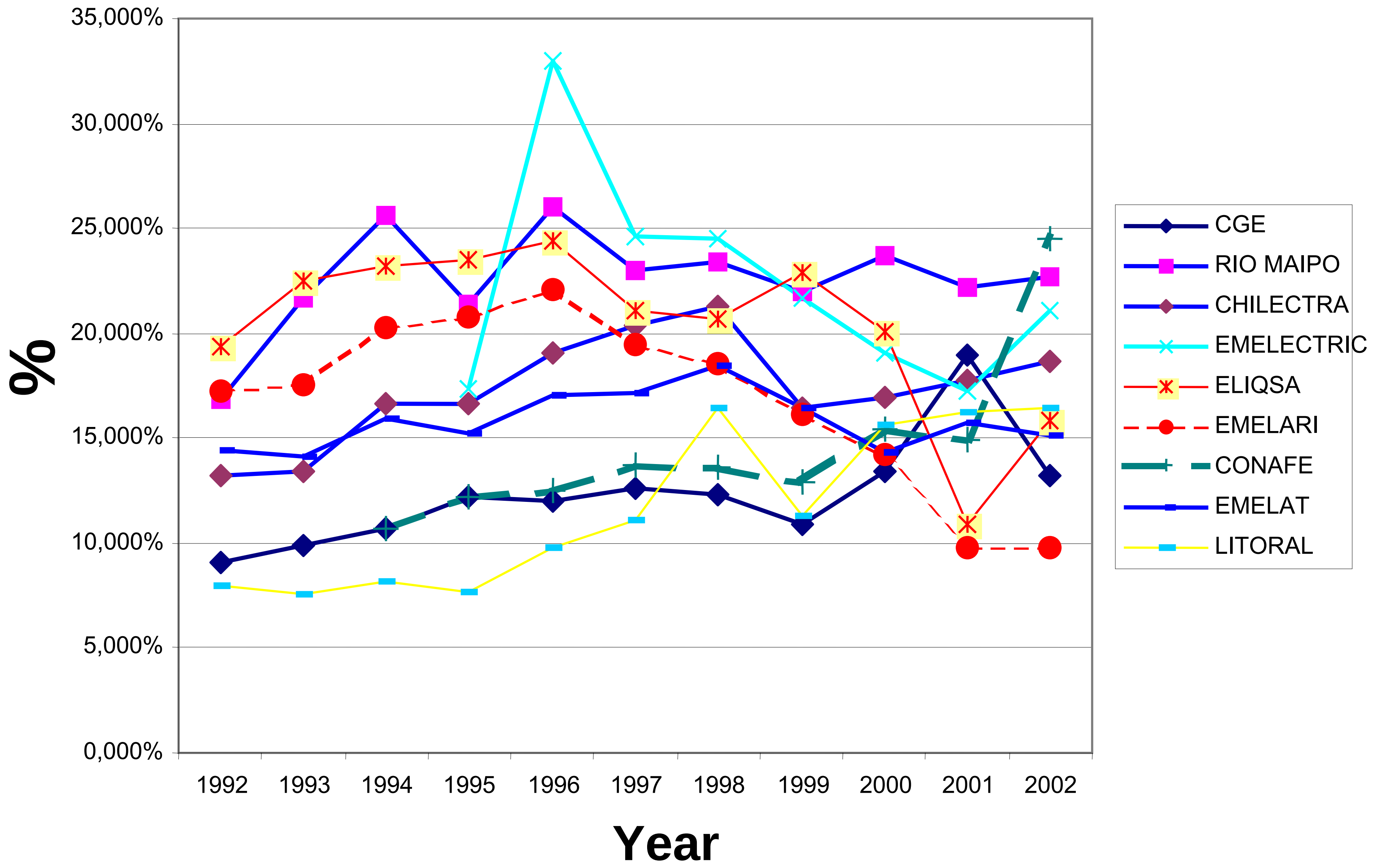
Clients increase 77% from 1992 to 2001

Ref: PA Consulting Group

Costs as determined by parties involved



Returns of distribution companies (Chile)



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New methods to determine efficiency

1968 Econometric methodology (introduction of deterministic frontier models)

1977 Stochastic frontier models and stochastic frontier analysis (SFA).

1978 Data envelopment analysis (DEA) with linear programming technique.

-establish which companies of a sample determine the envelopment area or efficient production frontier. The radial distance of a company to the frontier provides the efficiency measurement. Therefore, companies that are on the frontier (the ones that determine it) are considered efficient, while the ones that are far from the frontier are considered inefficient.

2003 DEA and Distribution Value Added

SEVERAL VARIABLES CONSIDERED IN RESEARCH

Variables	Sigla	Unidad
Valor Neto retornable total	VNRT	m$*
Valor Neto retornable alta tensión	VNRAT	m$*
Valor Neto retornable baja tensión	VNRBT	m$*
Costos de explotación**	CEXPLT	m$*
Costos de explotación alta tensión	CEXPLAT	m$*
Costos de explotación baja tensión	CEXPLBT	m$*
Energía comprada	ECOMP	kWh
Energía vendida total	EVENDT	kWh
Energía vendida en alta tensión	EVENDAT	kWh
Energía vendida en baja tensión	EVENDBT	kWh
Número de comunas	NCOMU	
Número de clientes	NCLTS	
Longitud total de líneas	KMT	Km
Longitud de líneas en alta tensión	KMAT	Km
Longitud de líneas en baja tensión	KMBT	Km
Potencia total coincidente	KWT	KW
Potencia total coincidente en horas de punta alta tensión	KWAT	KW
Potencia total coincidente en horas de punta baja tensión	KWBT	KW
Número de trabajadores	NTRAB	
Remuneraciones anuales	REMUN	m$*
Bienes muebles e inmuebles	BMI	m$*
Costo por compra de energía y potencia	CCOMP	m$*
Costos por pérdidas de energía y potencia***	CPERD	m$*

* : Miles de pesos del 31 de Diciembre de 1999

** : No considera los costos por compra de energía y potencia

***: De acuerdo a precio monómico definido por la CNE

VARIABLES UTILIZED IN DEA MODEL

Inputs				Outputs			
VADT	(1),	(2),	(3)	EVEND	(1),	(2),	(3)
KM T	(1),	(2),	(3)	KWT	(1)		
ENFAC			(3)	NCLTS	(1),	(2),	
NTRAB		(2),	(3)				
SALARIO		(2),	(3)				

$$\min \quad \theta_p$$

$$\text{subject to:} \quad \theta_p x_{ip} - \sum_{j=1}^{n} \lambda_j x_{ij} \geq 0 \qquad i = 1,2,\ldots,m$$

$$-y_{kp} + \sum_{j=1}^{n} \lambda_j y_{kj} \geq 0 \qquad k = 1,2,\ldots,s$$

$$\lambda_j \geq 0 \qquad j = 1,2,\ldots,n$$

where θ_p is the efficiency of the electrical distribution company under evaluation

VAD EFFICIENCY RESULTS

Empresa	Cod. SEG.	Modelo 1 θ	Modelo 2 θ	Modelo 3 θ
EMELARI	1	67.09	70.56	83.13
ELIQSA	2	60.54	80.68	100.00
ELECDA	3	79.71	98.85	99.96
EMELAT	4	46.97	43.83	87.51
EMEC	5	35.30	38.79	65.51
CHILQUINTA	6	60.86	45.65	51.42
CONAFE	7	54.66	62.88	100.00
EMELCA	8	56.39	95.86	95.92
LITORAL	9	41.53	58.98	58.98
CHILECTRA	10	100.00	100.00	100.00
RIO MAIPO	11	84.96	100.00	100.00
COLINA	12	96.39	70.68	95.69
TIL TIL	13	53.60	53.61	55.24
PUENTE ALTO	14	85.89	85.89	85.89
LUZANDES	15	100.00	100.00	100.00
PIRQUE	16	56.89	100.00	100.00
EMELECTRIC	17	26.63	44.32	45.83
CGE	18	49.59	68.04	100.00
COOPELAN	21	22.32	49.44	49.81
FRONTEL	22	19.46	37.13	42.52
SAESA	23	29.08	59.69	70.16
EDELAYSEN	24	44.66	55.15	57.01
EDELMAG	25	58.07	61.39	100.00
CODINER	26	23.92	71.49	71.77
ELECOOP	27	30.42	98.61	98.61
EDECSA	28	53.18	100.00	100.00
COOP CURICO	29	28.91	81.29	81.96
EMETAL	30	16.21	96.27	96.27
LUZLINARES	31	21.11	50.76	55.14
LUZPARRAL	32	21.57	100.00	100.00
COPELEC	33	17.77	30.92	33.92
COELCHA	34	21.72	47.50	47.50
SOCOEPA	35	38.39	79.17	79.17
COOPREL	36	50.01	60.96	60.96
CREO	39	61.06	100.00	100.00

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Other elements

Transmission and sub transmission networks

- -efficient replacement value
- -efficient model company
- -centralized transmission expansion
- -tariffs set every four years, indexation

Competitive gas supply wit no price regulation

- -natural gas competing with bottled liquefied gas
- -only security and quality regulated
- -market power supervision

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