

AN OVERVIEW ABOUT THE BRAZILIAN ELECTRICITY MARKET: OPTIMIZATION AND PRICING

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Overview

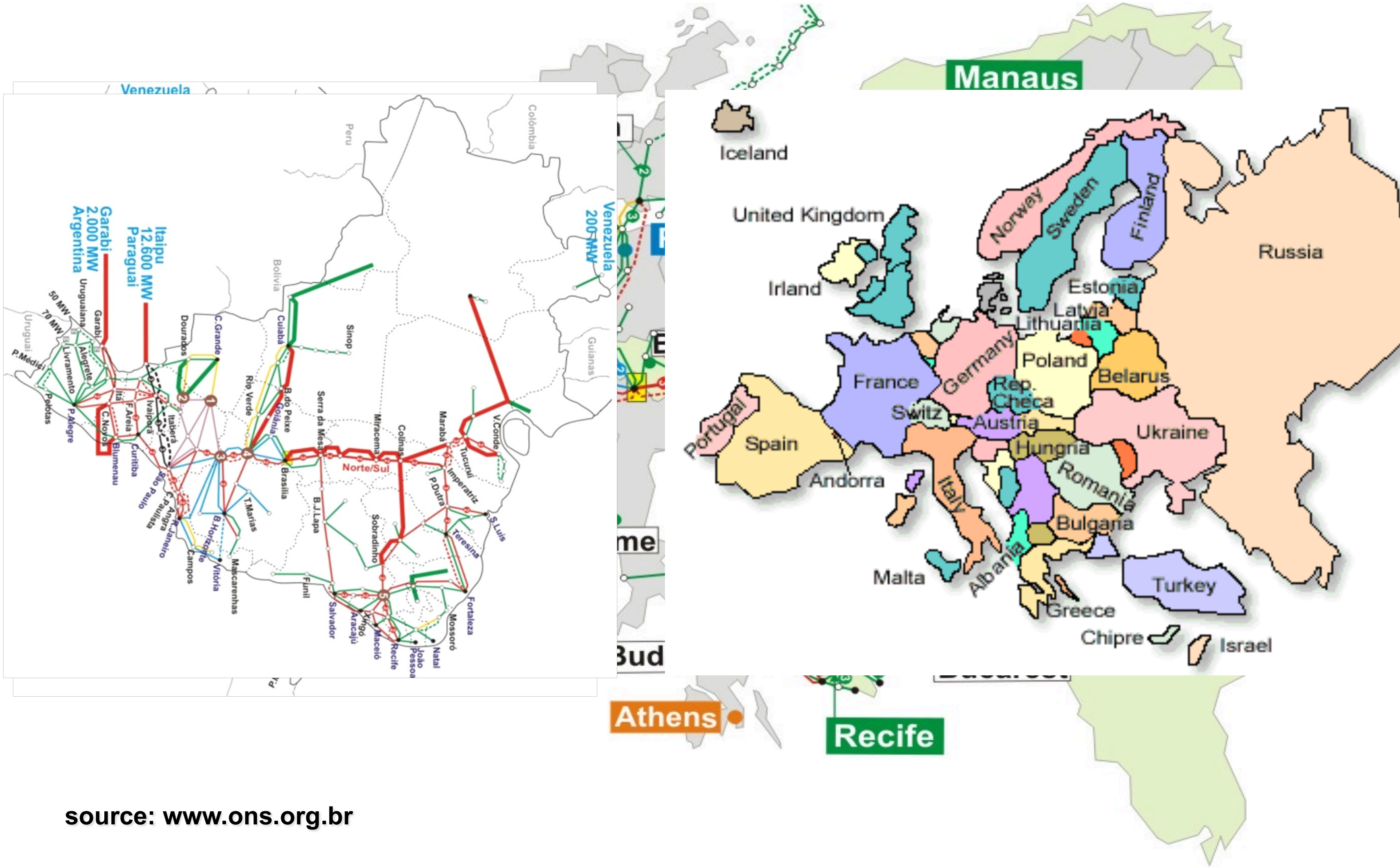
- Introduction
- The Brazilian Electric Power System
- Coordination and Optimization of Resources
- Pricing Formation in the Electricity Market
- Final Comments

Introduction

- Brazil is the largest country in South America and the 5th in the world
- 8th largest economy
- The population is approximately 212M
- Rich and diverse landscape with mountains, dense forests and major population centers

São Paulo (14.7 M)

Dimension of the Country



source: www.ons.org.br

The Brazilian Electric Power System

Background

- Before 1996 the **power sector was verticalized**
- The majority of assets were owned by the government
- Significant **inefficiency, lack of investments** and deterioration of the existing infrastructure
- Following the lead from England and Chile, Brazil took a **deep dive into deregulation** of the power sector

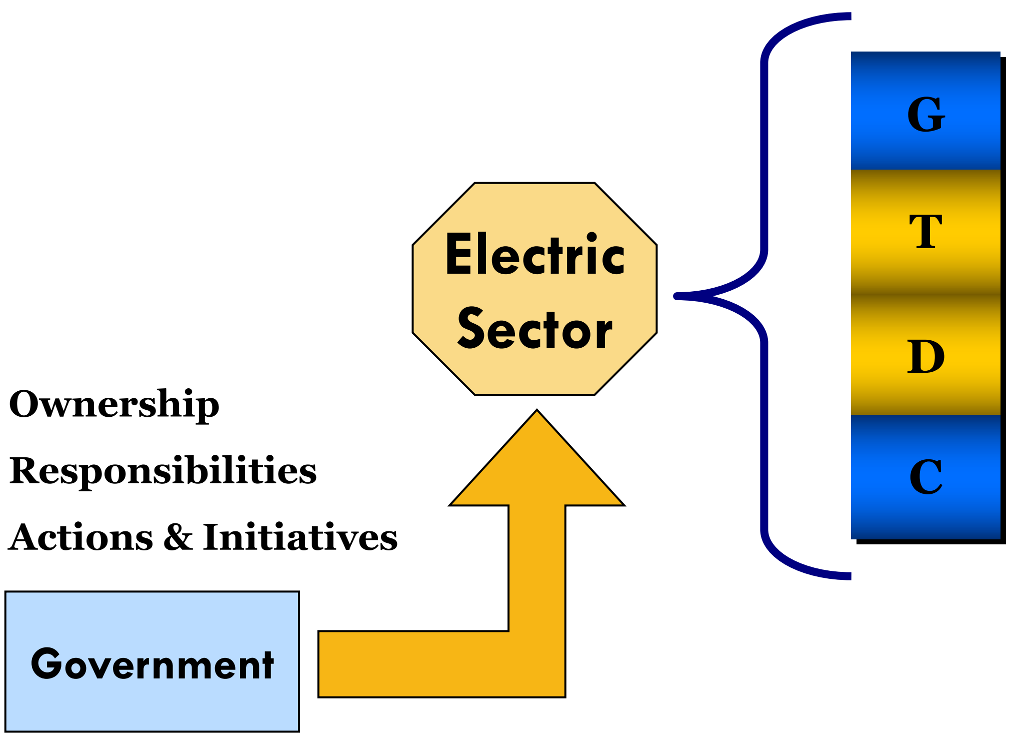
Private investments

+

Promote Competition

Deregulation of the Electric Sector

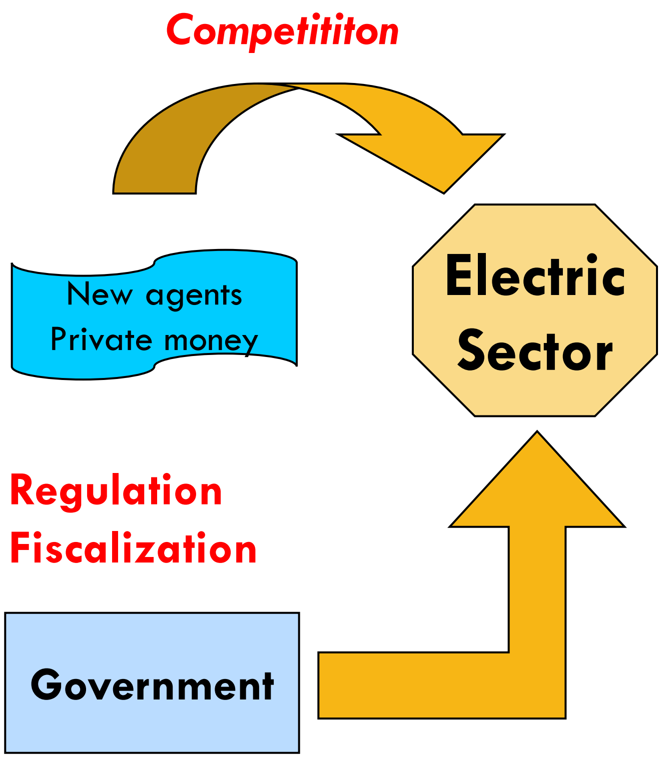
Electric sector model before 1996

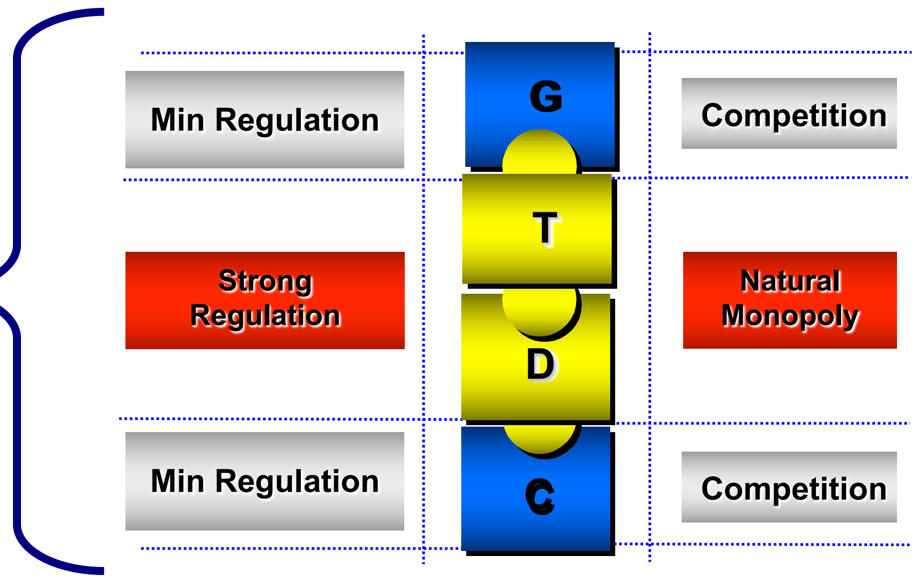


All the information, and the planning, coordination & operational processes were centralized. The government controlled the prices (that were mostly fixed)

Deregulation of the Electric Sector (cont.)

Electric sector model after 1996



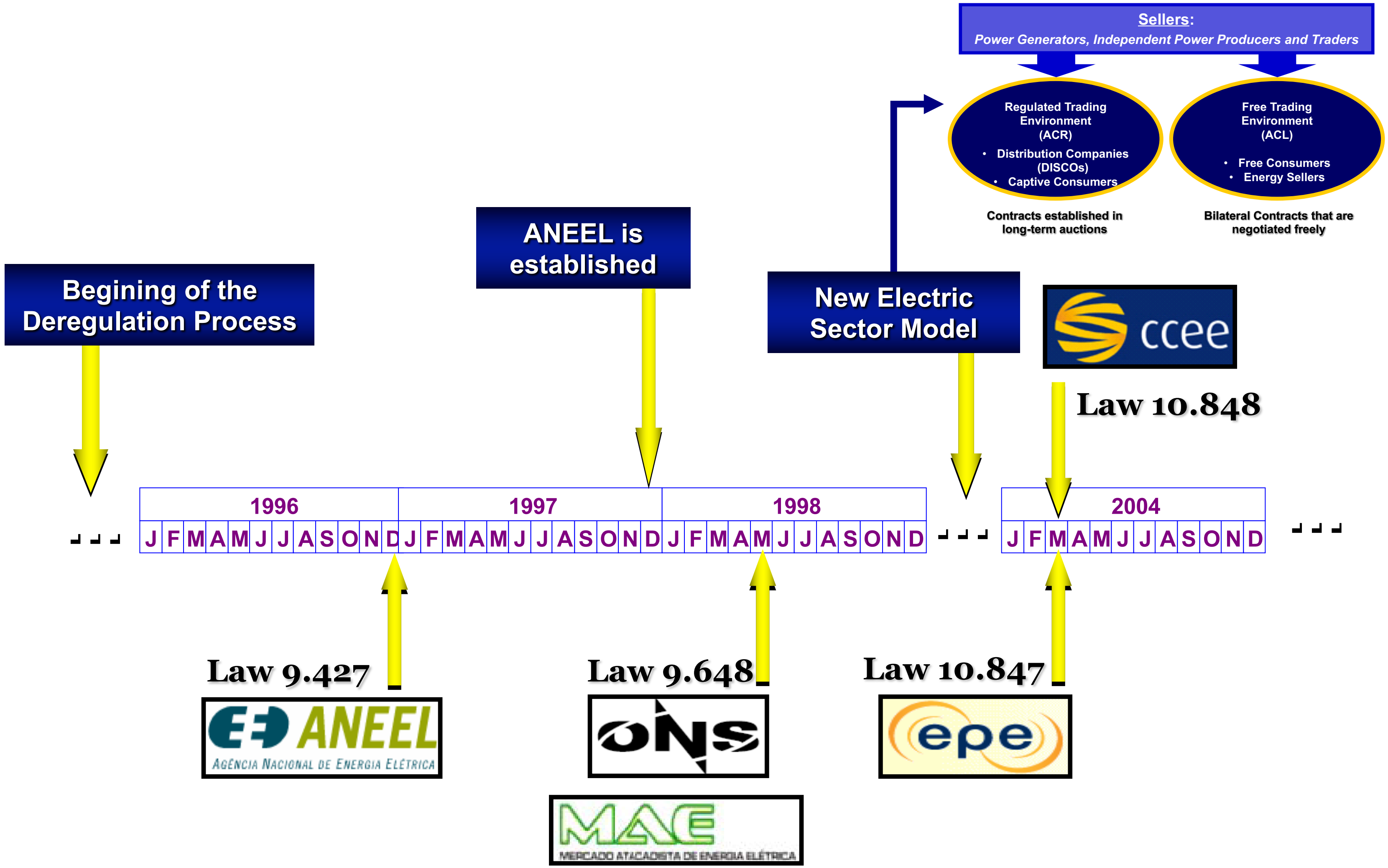


Electricity prices became fundamental variable for G and C

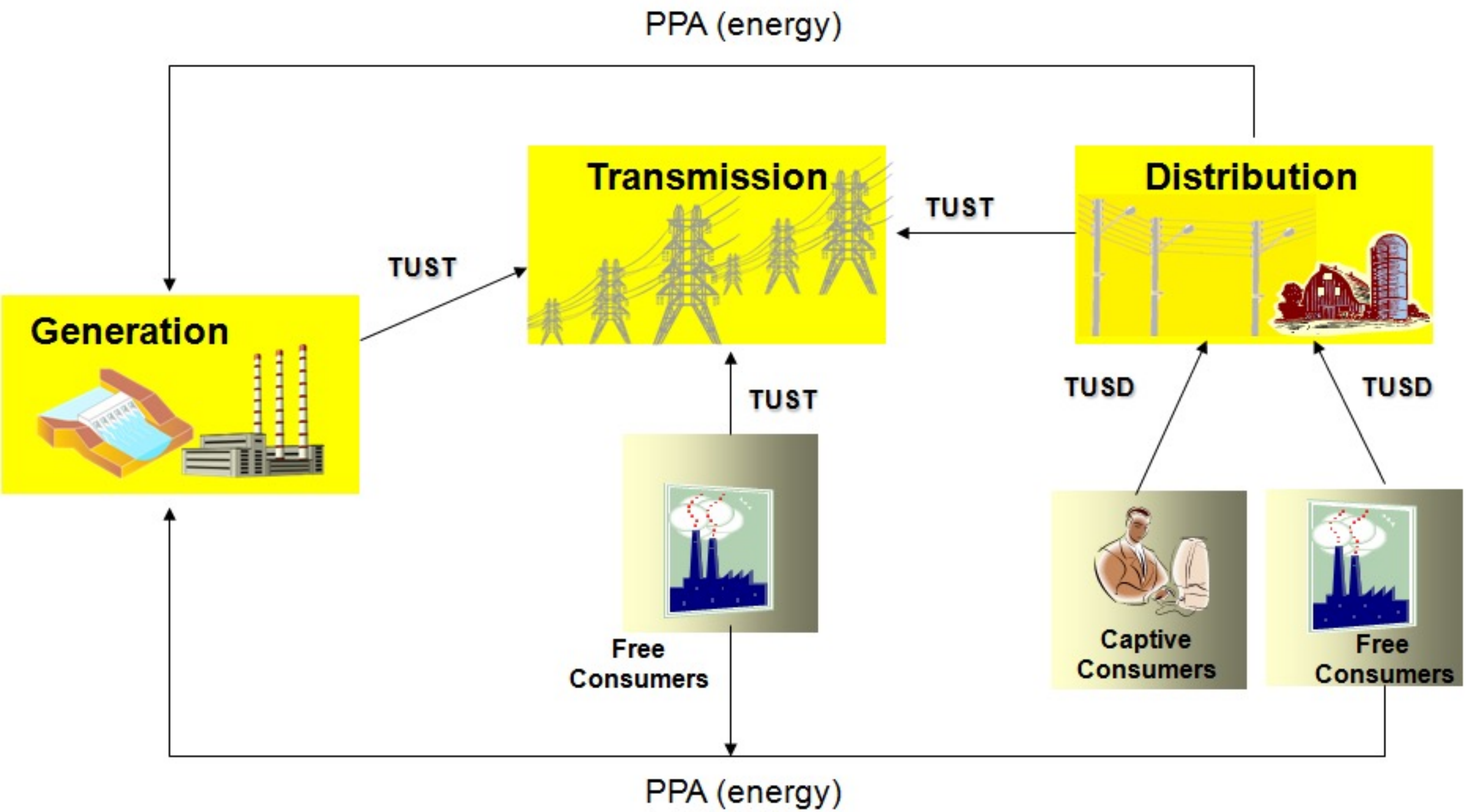
Electricity tariffs became key for T and D and also affect G

Why prices are important for G and C?

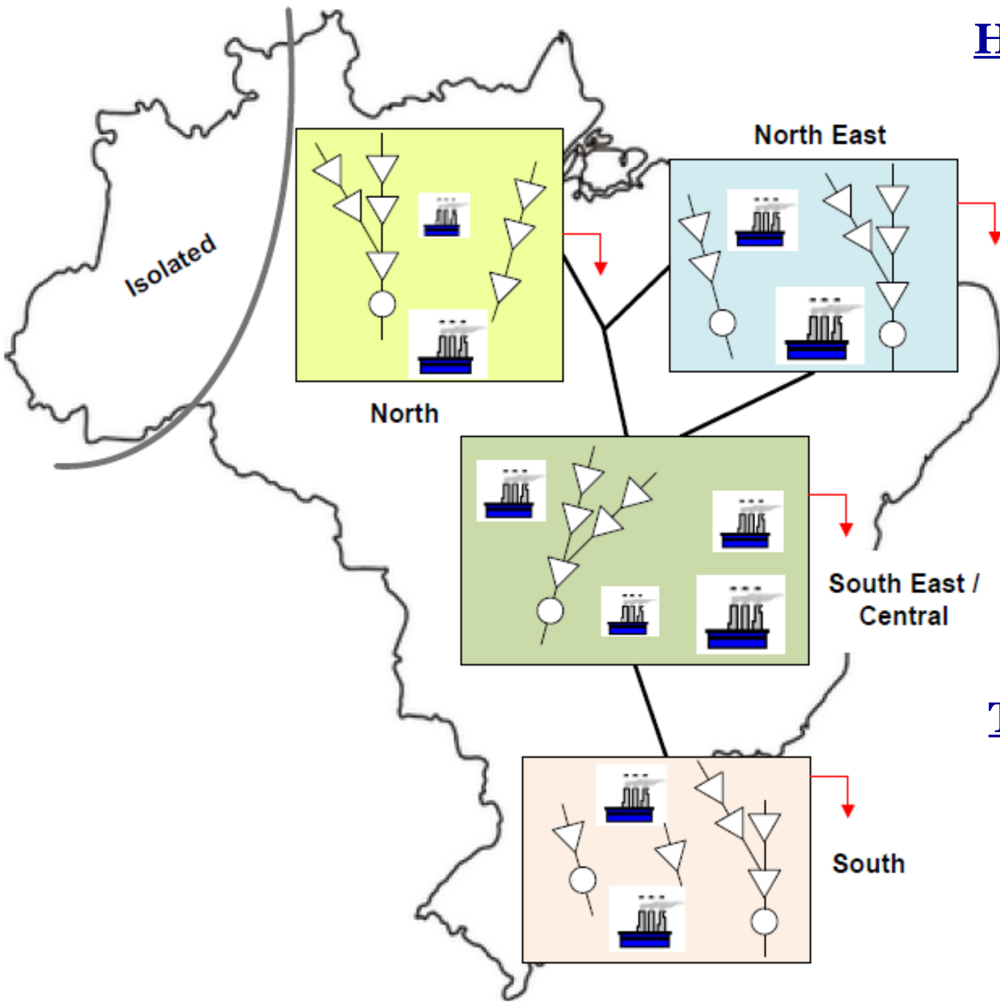
Electric Sector Milestones



Relationships Among Agents



Brazilian Interconneted Power System (SIN)



Hydropower plants

Represent ≅ 68% of the generation capacity

Concentrated in 12 river basins

Far away from load centers

Thermal plants

Represent ≅ 14% of the generation capacity

Near load centers

Complement hydro and other sources

Transmission network

Integrate resources

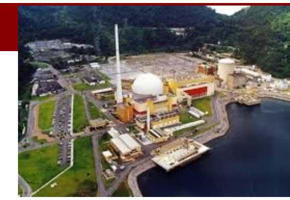
Allow for international exchanges

Enable resource optimization

Electricity Generation Capacity in 2018

Diesel

Coal



Nuclear

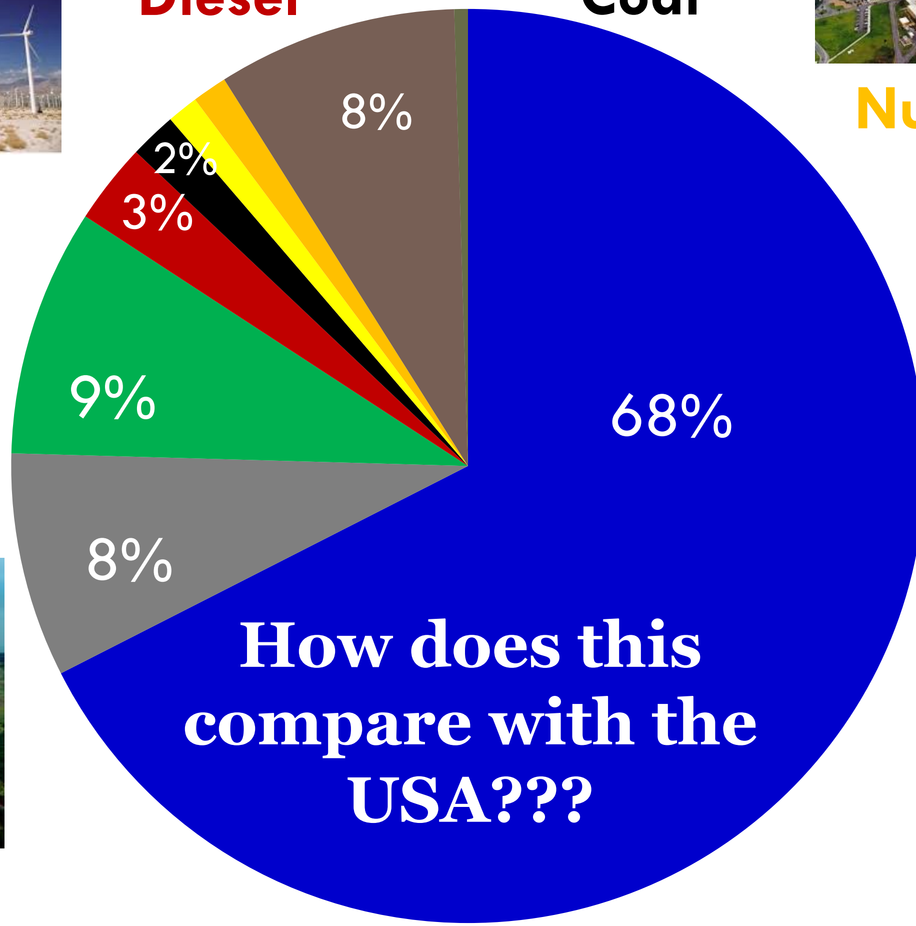
Wind

Biomass

Natural gas

Solar

Hydro



Total Installed Capacity 161.5GW

■ Hydro ■ Ngas ■ Wind ■ Oil & Diesel ■ Coal ■ Solar ■ Nuclear ■ Biomass ■ Other

http://ons.org.br/paginas/sobre-o-sin/o-sistema-em-numeros

Brazilian Interconneted Power System (SIN)

North (N)
- Energy exporter
- New run-of-river hydro
- Tendency to increase exports

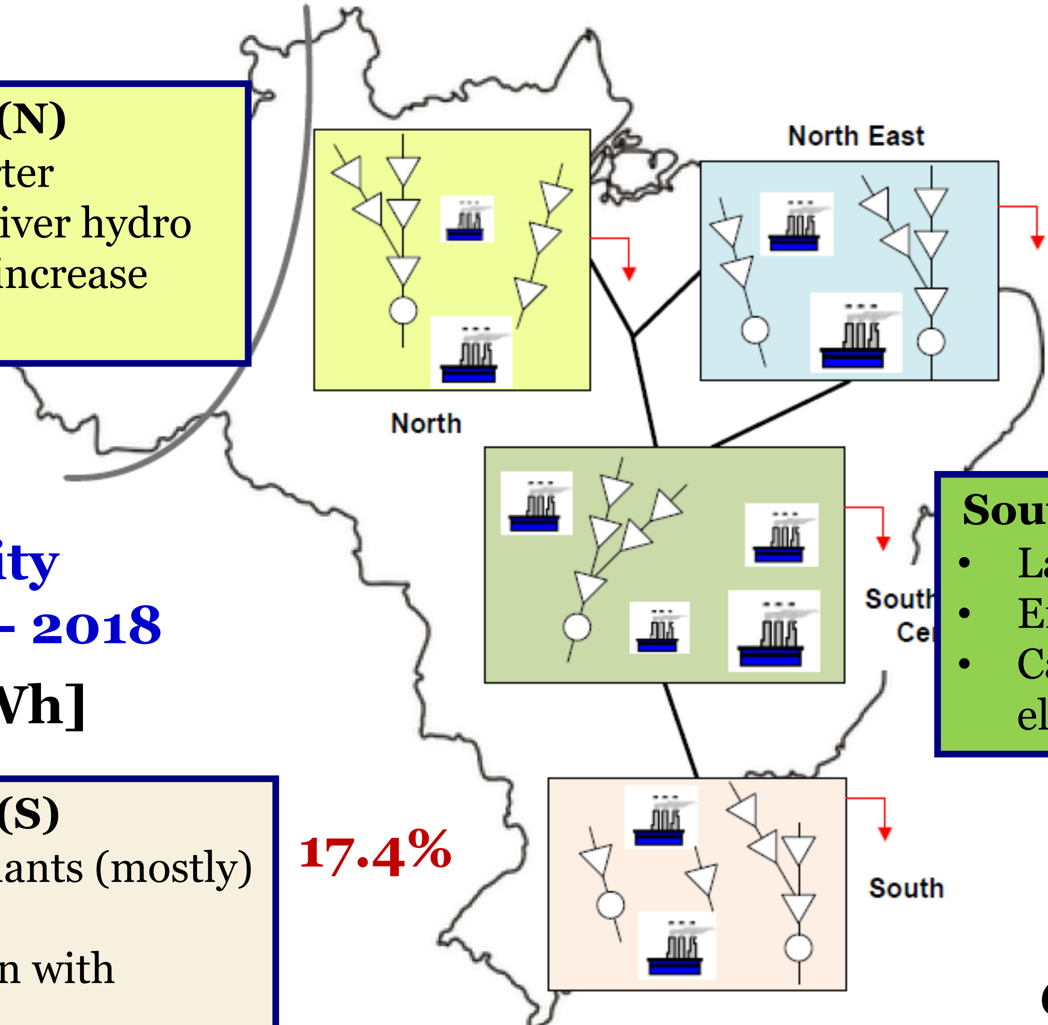
7.6%

Electricity Generation - 2018

581.9 [TWh]

South (S)
- Run-of-river plants (mostly)
- Export to SE
- Interconnection with Argentina

17.4%



Northeast (NE)
- ↑ electricity demand
- ↑ Wind Farms
- Import from SE

16.3%

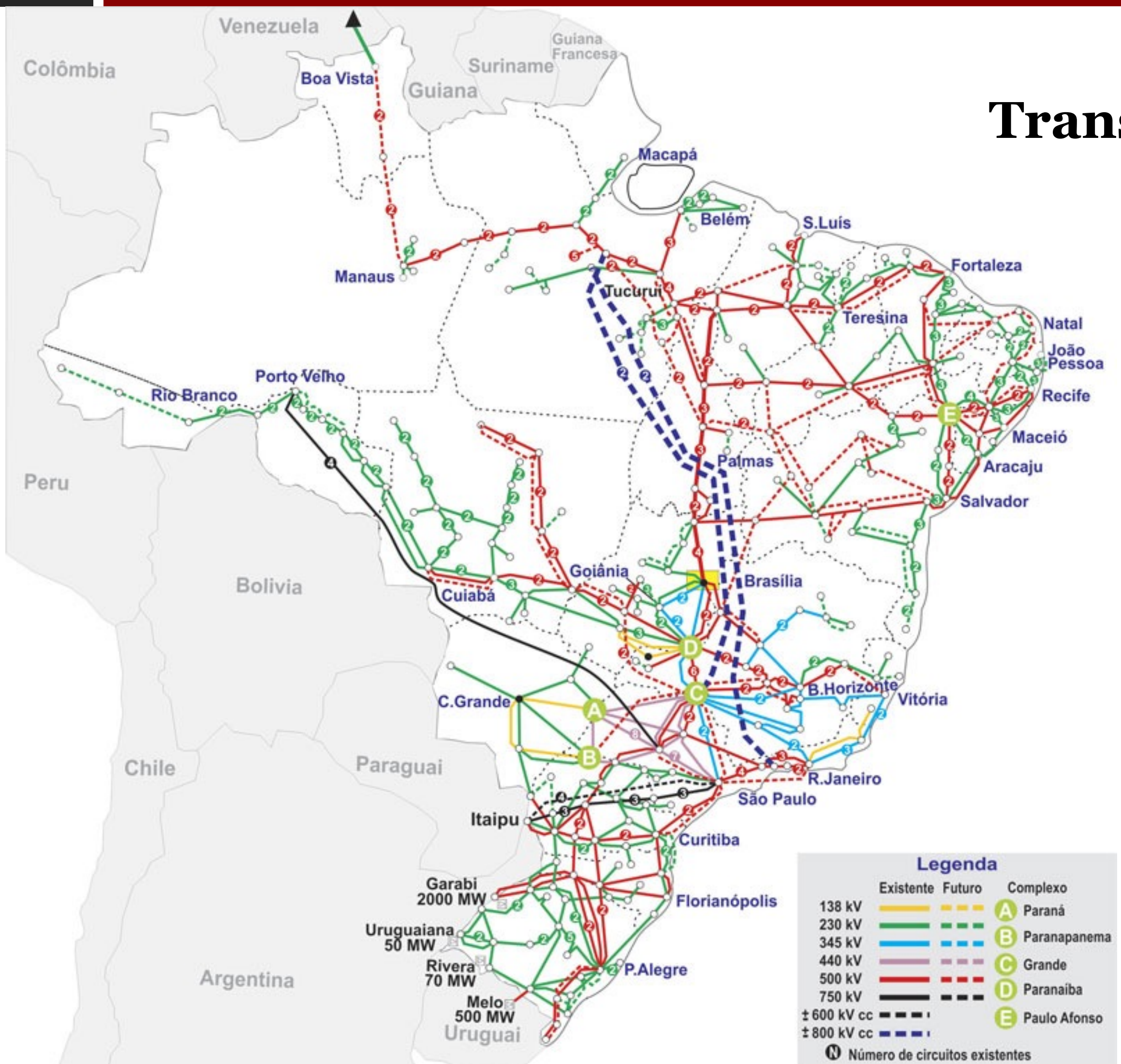
Southeast / Central (SE)
- Largest load centers
- Energy importer
- Capabilities to store electricity

58.7%

Load - 2018

63.8 [GWavg]

Transmission Interconnections



Transmission Interconnection Capacities

SE – S: 16.3 GW

SE – NE: 9.7 GW

SE – N: 17.9 GW

NE – N: 12.5 GW

> 141,000 km of high voltage transmission lines

How many tours around the world?

source: www.ons.org.br

Schematic Diagram of the Hydropower plants in Operation in the Brazilian SIN - 2019

ONS Operador Nacional do Sistema Elétrico

Potência Instalada

31 Dez	Hidroelétrica(*) (MW)	Percentual do SIN (*)
2018	97.144	62,3
2019	100.641	62,5
2020	101.863	61,7
2021	101.899	60,9
2022	101.899	60,3
2023	101.961	59,2

(*) Valores sujeitos a alteração em função da evolução do cronograma de expansão do sistema.

Bacias Hidrográficas

Código de cores das usinas

- Amazonas
- Atlântico NE Ocidental
- Atlântico NE Oriental
- Parnaíba
- Tocantins-Araguaia
- São Francisco
- Atlântico Leste
- Atlântico Sudeste
- Atlântico Sul
- Paraguai
- Paraná
- Uruguai

Legenda

- Usina com Reservatório
- Usina com Reservatório Futura
- Usina a Fio d'Água
- Usina a Fio d'Água Futura
- Usina em Construção
- Reservatório
- Usina de Bombeamento

Usina existente: Potência efetiva
Usina futura: Potência outorgada

Planejamento da Operação Energética

Legenda

Aproveitamentos Existentes

- 72 com reservatório
- 88 a fio d'água
- 4 bombeamento

Usinas Futuras / em Construção

- 1 com reservatório
- 2 a fio d'água

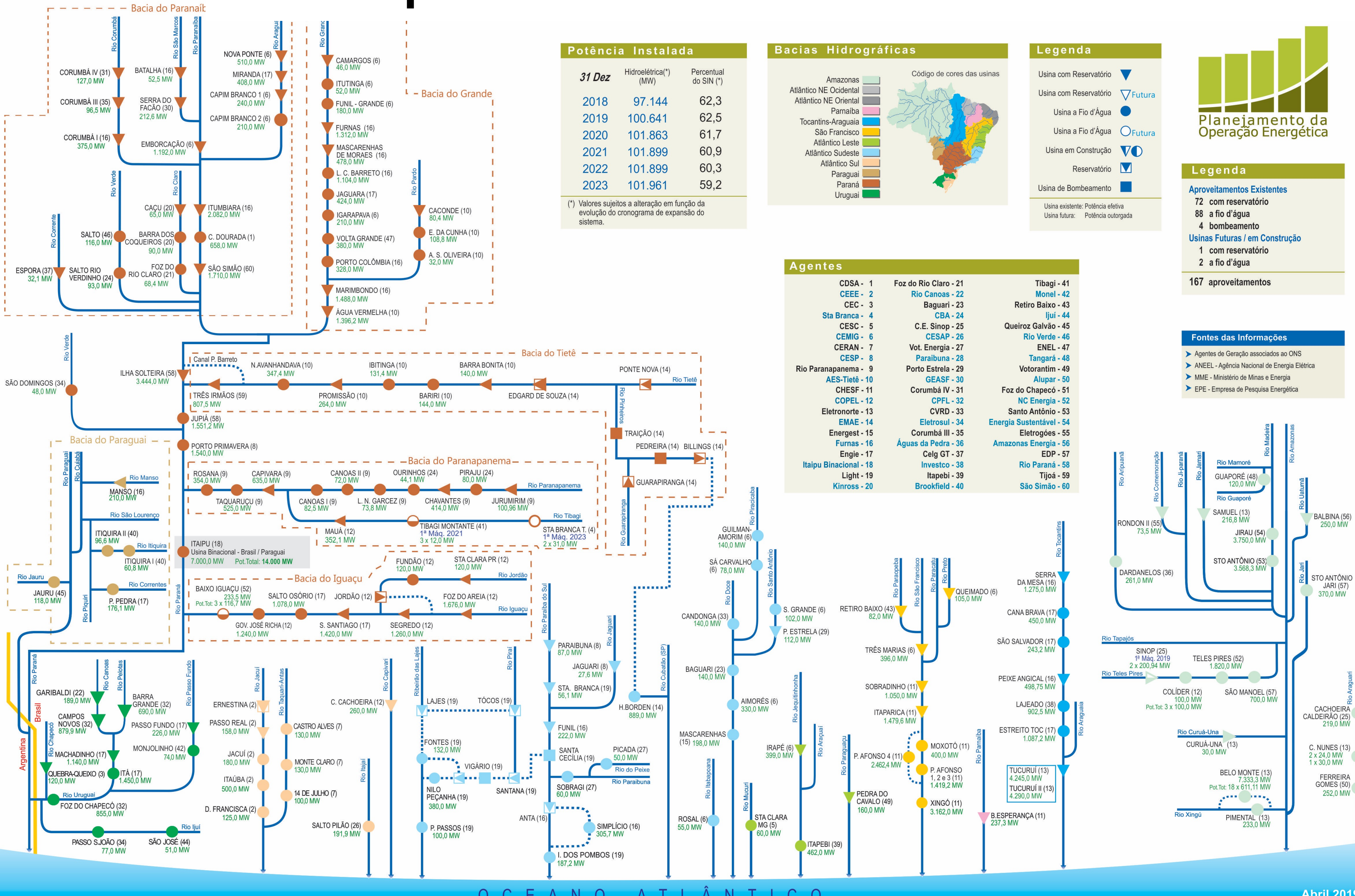
167 aproveitamentos

Agentes

CDSA - 1	Foz do Rio Claro - 21	Tibagi - 41
CEEE - 2	Rio Canoas - 22	Monel - 42
CEC - 3	Baguari - 23	Retiro Baixo - 43
Sta Branca - 4	CBA - 24	Ijuí - 44
CESC - 5	C.E. Sinop - 25	Queiroz Galvão - 45
CEMIG - 6	CESAP - 26	Rio Verde - 46
CERAN - 7	Vot. Energia - 27	ENEL - 47
CESP - 8	Paraibuna - 28	Tangará - 48
Rio Paranapanema - 9	Porto Estrela - 29	Votorantim - 49
AES-Tietê - 10	GEASF - 30	Alupar - 50
CHESF - 11	Corumbá IV - 31	Foz do Chapecó - 51
COPEL - 12	CPFL - 32	NC Energia - 52
Eletronorte - 13	CVRD - 33	Santo Antônio - 53
EMAE - 14	Eletrosul - 34	Energia Sustentável - 54
Energest - 15	Corumbá III - 35	Eletrogóes - 55
Furnas - 16	Águas da Pedra - 36	Amazonas Energia - 56
Engie - 17	Celg GT - 37	EDP - 57
Itaipu Binacional - 18	Investco - 38	Rio Paraná - 58
Light - 19	Itapebi - 39	Tijoá - 59
Kinross - 20	Brookfield - 40	São Simão - 60

Fontes das Informações

- Agentes de Geração associados ao ONS
- ANEEL - Agência Nacional de Energia Elétrica
- MME - Ministério de Minas e Energia
- EPE - Empresa de Pesquisa Energética



Coordination and Optimization of Resources

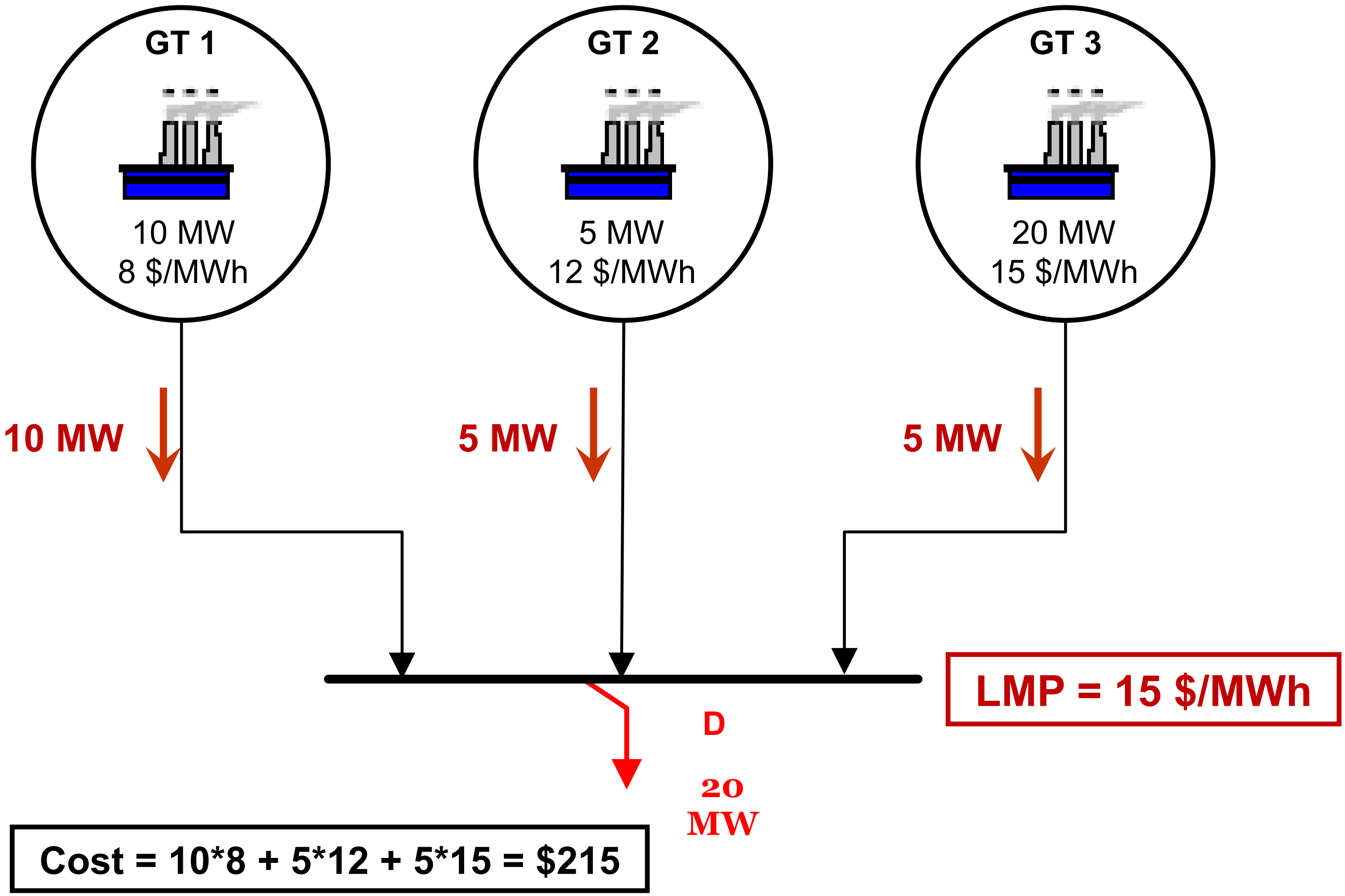
Renewables Integration

- **Renewable power** sources became a key aspect around the world by **disrupting old frontiers**
- These energy sources are linked to **sustainable development** that is one of the main goals of the modern society these days
- **The raise of renewable power installed** capacity demands new studies about its effects
- **Modeling and decision making techniques** are essential for operational and planning actions

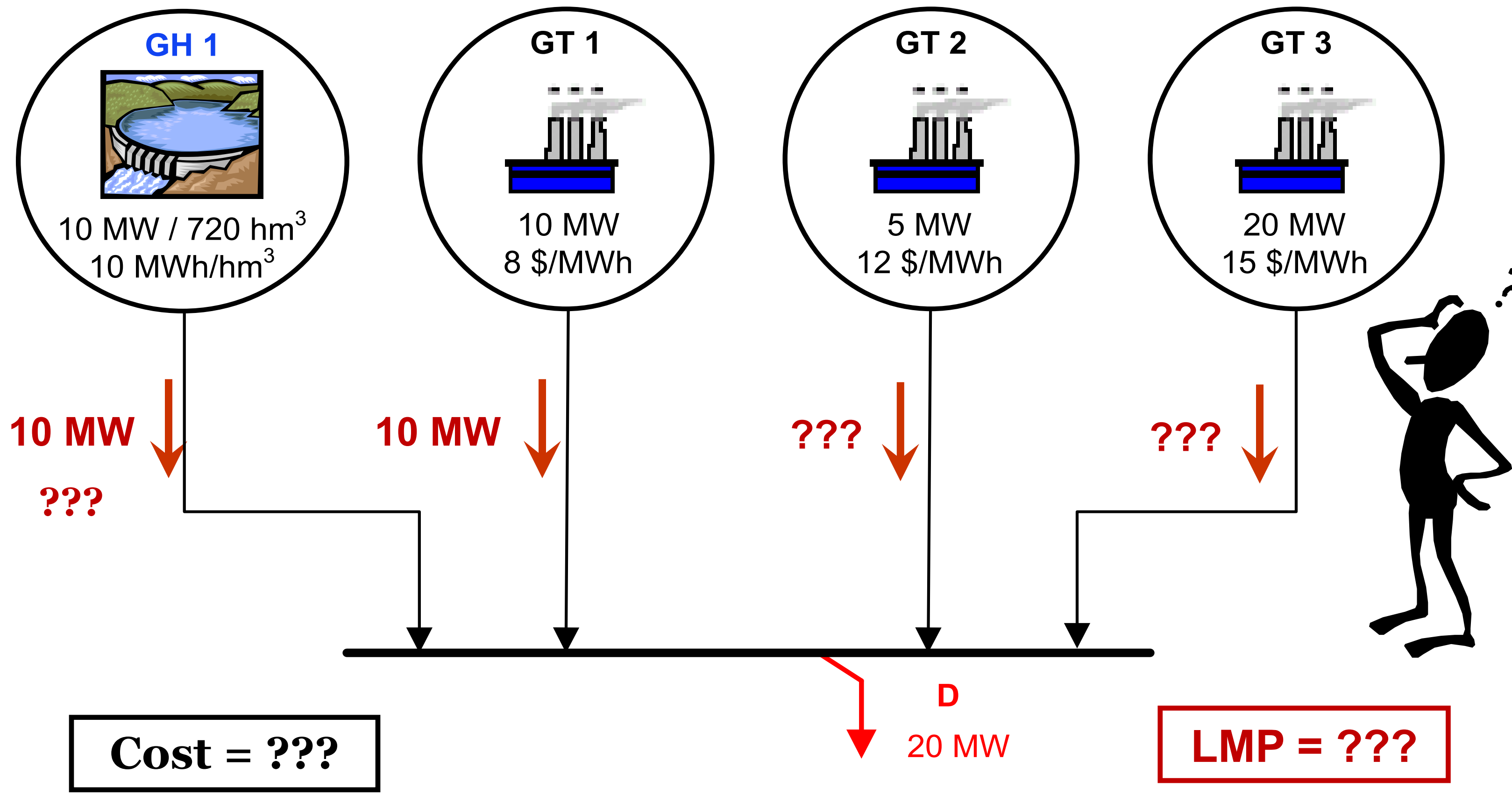
Coordination of Resources

- The main problem with renewable power is its dependence on natural resources (**may not be available when necessary**)
- Hydropower is an exception of these restrictions, since **reservoirs can store water and control generation**
- Countries such Brazil, Norway, Canada and also USA regions (BPA concession area, Western Texas) present **highly dominant renewable generation matrix**
- In this context one important problem addressed in many places is the **hydro-thermal coordination problem (HTCP)**, and its variations to accommodate other renewables

Economic Dispatch – Thermal



Hydro-thermal Coordination (2stages)



$\text{Cost}_{t1} = 10*0 + 10*8 = \$80$

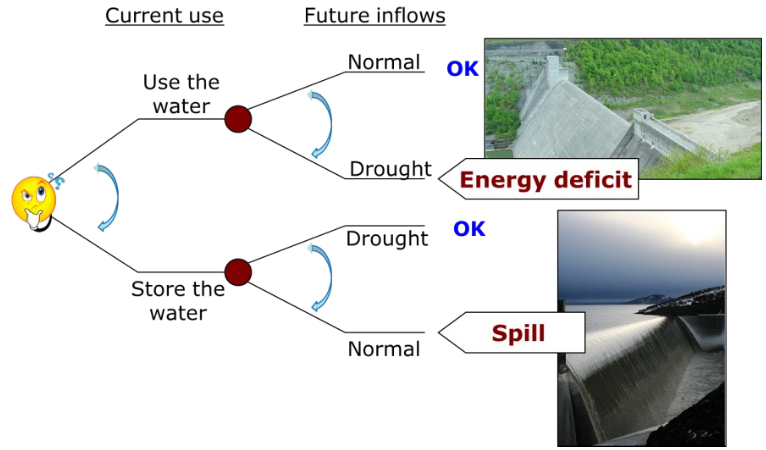
$\text{Cost}_{t2} = 10*8 + 5*12 + 5*15 = \$215$

$\text{Cost}_{t1} = 5*0 + 10*8 + 5*12 = \$140$

$\text{Cost}_{t2} = 5*0 + 10*8 + 5*12 = \$140$

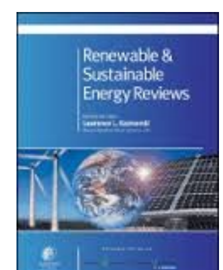
Stochastic Hydro-thermal Coordination

- Find the sequence of **hydro releases** and **thermal plant dispatches** for a planning horizon to match system demand
  - Resource management
  - Input variable forecasting
  - Operational aspects



- Basic economic criterion
  - **Minimize operational costs** (present + expected future)
- Usually modeled and solved using stochastic programming (optimization) techniques

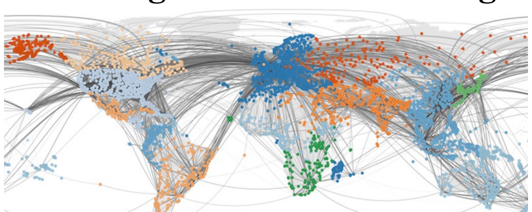
de Queiroz, A.R., (2016) Stochastic Hydro-thermal Scheduling Optimization: An Overview, Renewable and Sustainable Energy Reviews, 62: 382-395



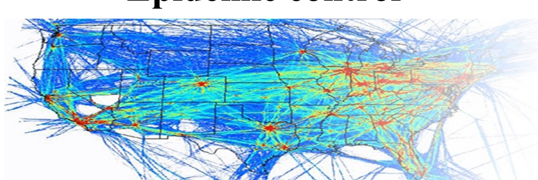
A Little About Stochastic Programming

- **Stochastic programing** (SP) is used as a tool for modeling **optimization** problems under **uncertainty**
- This operations research area was born in the 1950s "Linear programming under uncertainty" (**Dantzig, 1955**)

Power generation scheduling



Epidemic control

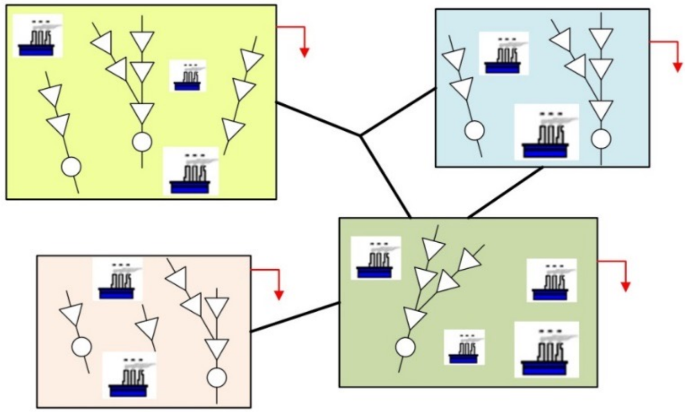


Transportation planning

- Real problems constantly include parameters that are unknown when decisions should be made
- SP models rely on the assumption that **probability distributions** are known or can be estimated
- There are different classes of SPs, and our focus is on **multi-stage stochastic linear programs** (SLP-t)
- Decisions have to be made at different time stages and there is a dynamic link between stages

Variables & Parameters

- Sets:
  - Set of **hydro power plants:** $i \in I$
  - Set of **thermal power plants:** $\ell \in L$
  - Set of time stages: $t \in T$
  - Set of electrical **subsystems:** $r \in R$
  - Set of **curtailment levels:** $k \in K$
  - Subset of upstream reservoirs: M_i
- Decision variables:
  - **Hydro generation:** GH_i^t
  - **Spilled volumes:** S_i^t
  - **Water volume storage:** x_i^t
  - **Thermal generation:** GT_ℓ^t
  - **Energy transfers between regions:** $F_{r\,r'}^t$
  - **Load curtailment:** GD_k^t



- Parameters:
  - Future water inflows: $b_t, b_{t+1}, \ldots, b_T$ **(uncertainty)**
  - Electricity demand at region r: D_{tr}
  - Bound limits: $\underline{X}$, $\overline{X}$

HTCP Model Formulation for Stage-t

Present Cost — **Expected Future Cost**

$$h_t(x^{t-1}, b_t^{\omega}) = \min \sum_{\ell \in L} c_\ell^t GT_\ell^t + \sum_{k \in K} u_k^t GD_k^t + \frac{1}{(1+\beta)} \mathbb{E}_{b_{t+1}|b_1,\ldots,b_t} h_{t+1}(x^t, b_{t+1})$$

Water Balance

$$\text{s.t.} \quad x_i^t + GH_i^t + S_i^t = x_i^{t-1} + b_{t+1}^{\omega} + \sum_{j \in M_i} (GH_j^t + S_j^t) \quad \forall i \in I$$

Demand Satisfaction

$$\sum_{i \in I_r} \rho_i GH_i^t + \sum_{\ell \in L} GT_\ell^t + \sum_{k \in K} GD_k^t - \sum_{\substack{r' \in R \\ r' \neq r}} F_{r\,r'}^t + \sum_{\substack{r' \in R \\ r' \neq r}} F_{r\,r'}^t = D_{tr} \quad \forall r \in R$$

Simple Bounds

$$\underline{x}_i^t \le x_i^t \le \bar{x}_i^t \quad \forall i \in I$$

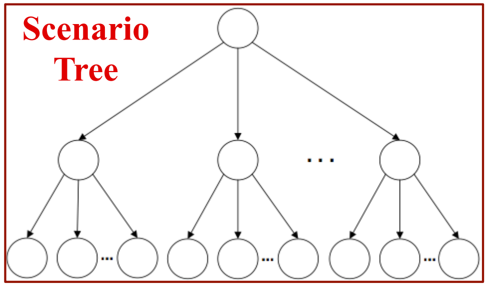
$$0 \le GH_i^t \le \overline{GH_i^t} \quad \forall i \in I$$

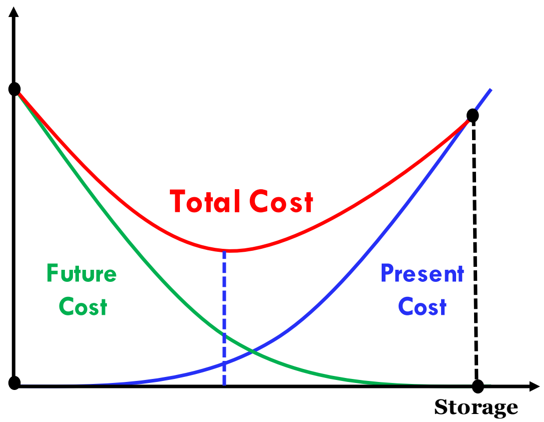
$$0 \le S_i^t \quad \forall i \in I$$

$$\underline{GT_\ell^t} \le GT_\ell^t \le \overline{GT_\ell^t} \quad \forall \ell \in L$$

$$0 \le GD_k^t \quad \forall k \in K$$

$$0 \le F_{r\,r'}^t \le \overline{F_{r\,r'}^t} \quad \forall (r, r') \in R$$





HTCP Model with Wind Penetration

Present Cost **Future Cost Function**

$$h_t(x^{t-1}, b_t^{\omega}) = \min \sum_{\ell \in L} c_\ell^t GT_\ell^t + \sum_{k \in K} u_k^t GD_k^t + \frac{1}{(1+\beta)} \mathbb{E}_{b_{t+1}|b_1,\ldots,b_t} h_{t+1}(x^t, b_{t+1})$$

Water Balance

$$\text{s.t.} \quad x_i^t + GH_i^t + S_i^t = x_i^{t-1} + b_{t+1}^{\omega} + \sum_{j \in M_i} \left(GH_j^t + S_j^t\right) \quad \forall i \in I$$

$$\sum_{i \in I_r} \rho_i GH_i^t + \sum_{\ell \in L} GT_\ell^t + \sum_{k \in K} GD_k^t - \sum_{\substack{r' \in R \\ r' \neq r}} F_{r\,r'}^t + \sum_{\substack{r' \in R \\ r' \neq r}} F_{r\,r'}^t = D_{tr} \quad \forall r \in R$$

Demand Satisfaction

$$+ \sum_{v \in V_r} w_v^t$$

$$w_v^t \leq n \frac{1}{2} \sigma \cdot A \cdot {ws_{vt}^{\omega}}^3 \cdot C_p^t \quad \forall v \in V$$

Maximum wind power generation

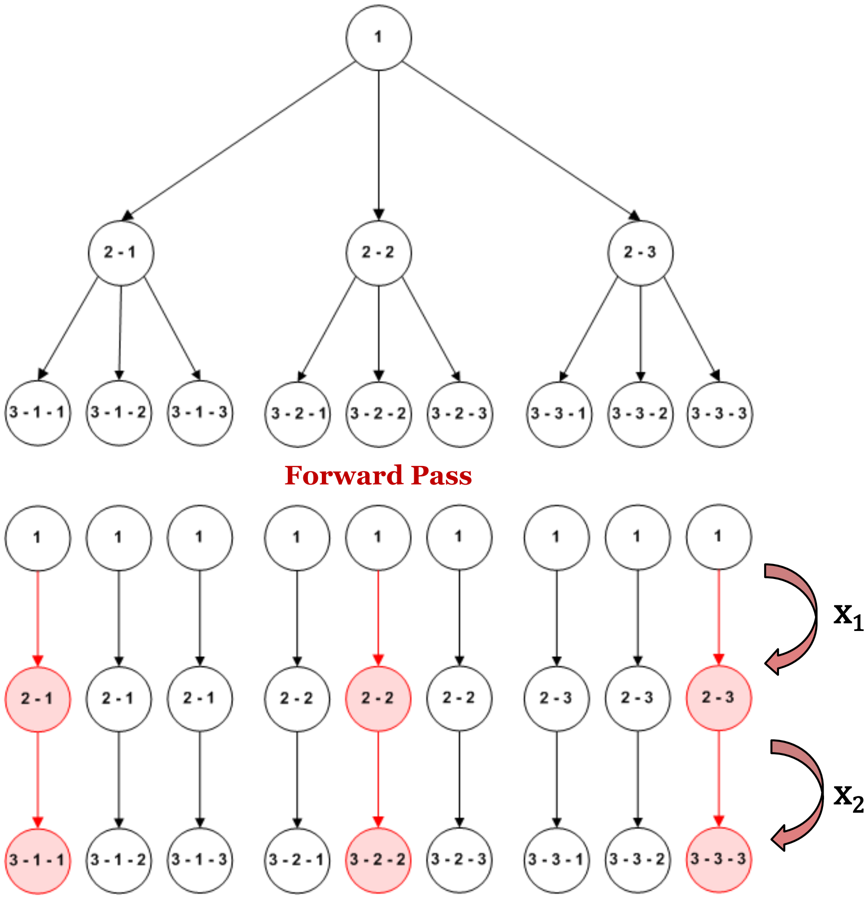
Simple bounds

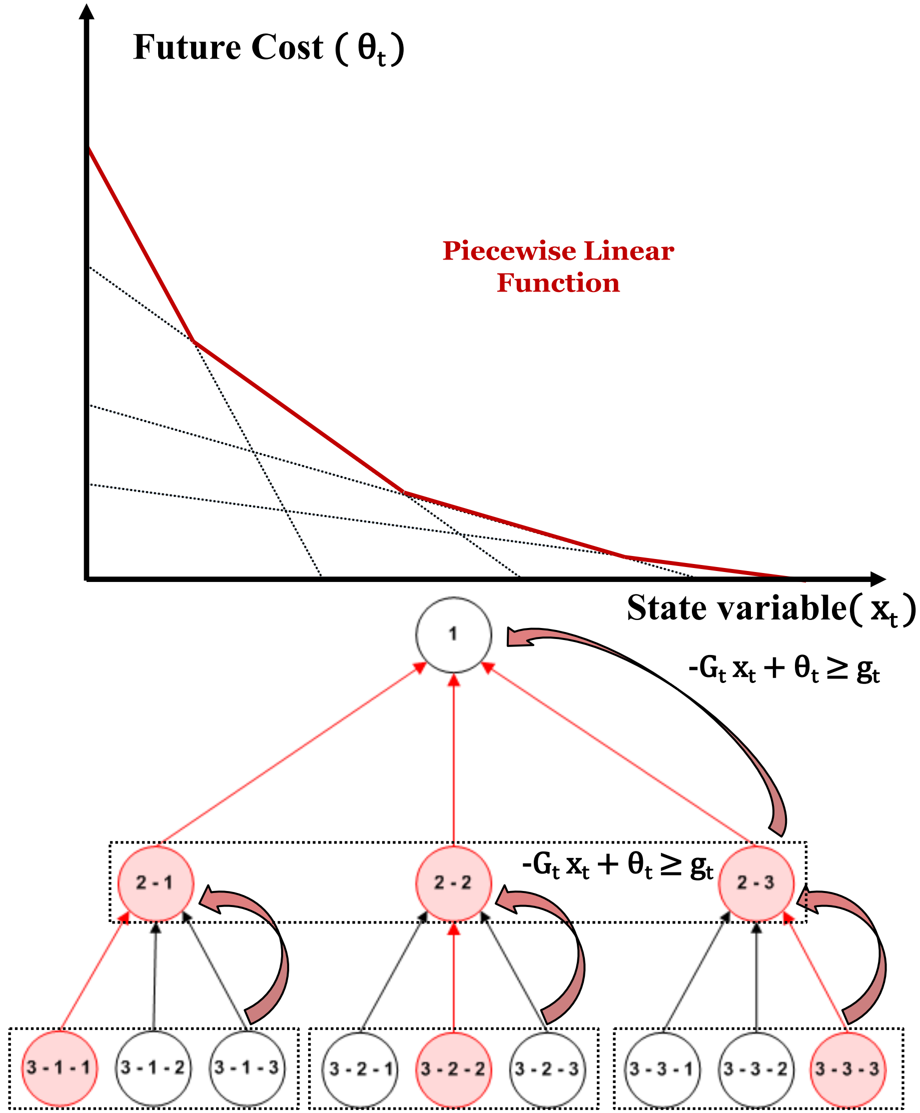
Silva, S.R., de Queiroz, A.R., Lima, L.M.M., Lima, J.W.M., (2014) Effects of Wind Penetration in the Scheduling of a Hydro-Dominant Power System, IEEE PES General Meeting

Incorporate Solar PV, other storage technologies and handle different uncertainty time scales & operational issues

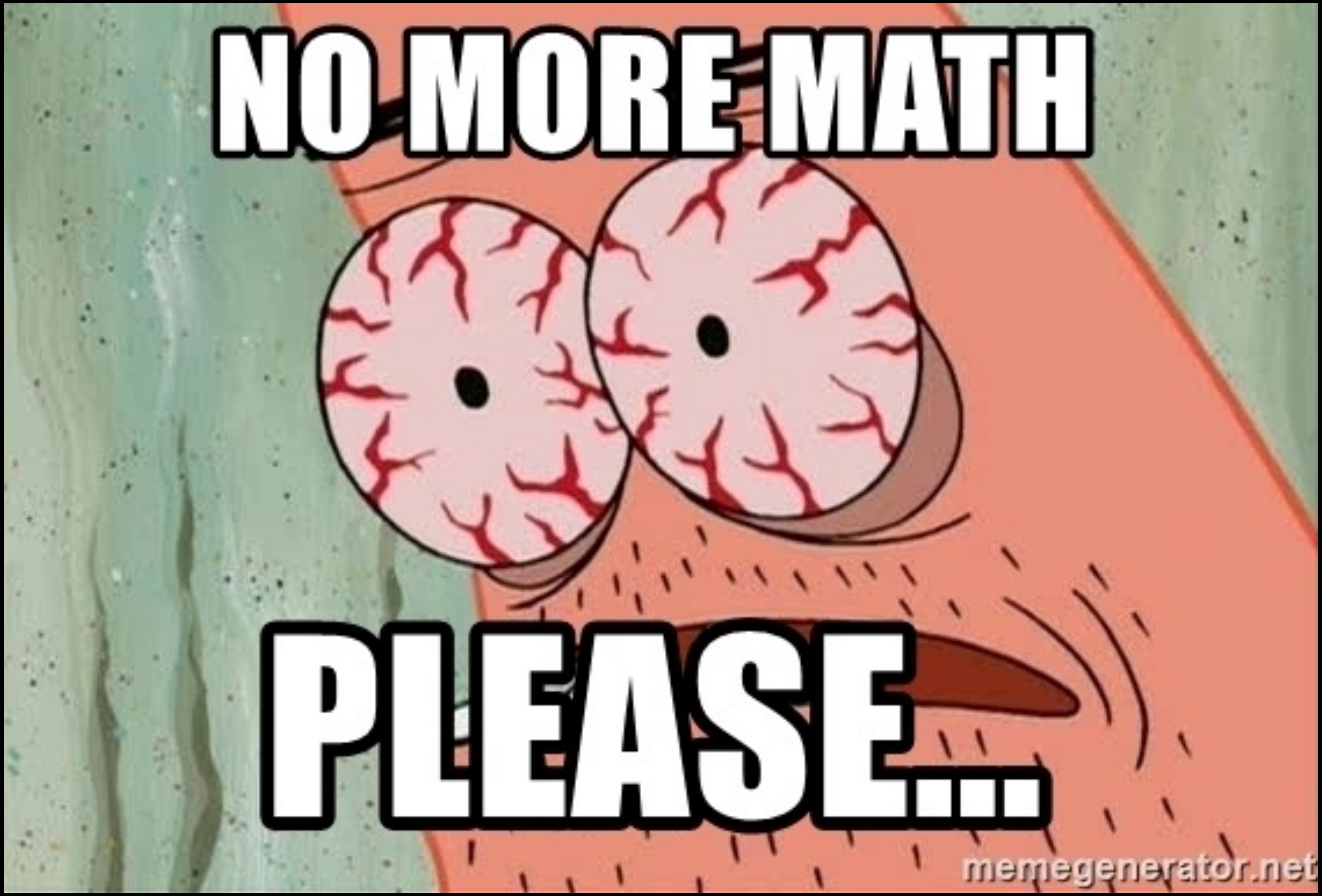
IEEE PES Power & Energy Society IEEE PES GENERAL MEETING

Sampling-based Decomposition Algorithm





de Queiroz, A.R., Morton, D.P., (2013) Sharing Cuts under Aggregated Forecasts when Decomposing Multi-stage Stochastic Programs, Operations Research Lett, 41(3): 311-316


NO MORE MATH
PLEASE...
memegenerator.net

Pricing Formation in the Electricity Market

The Brazilian Electricity Market

<u>Sellers</u>:

Power Generators, Independent Power Producers and Traders

Regulated Trading Environment (ACR)

- **Distribution Companies (DISCOs)**
- **Captive Consumers**

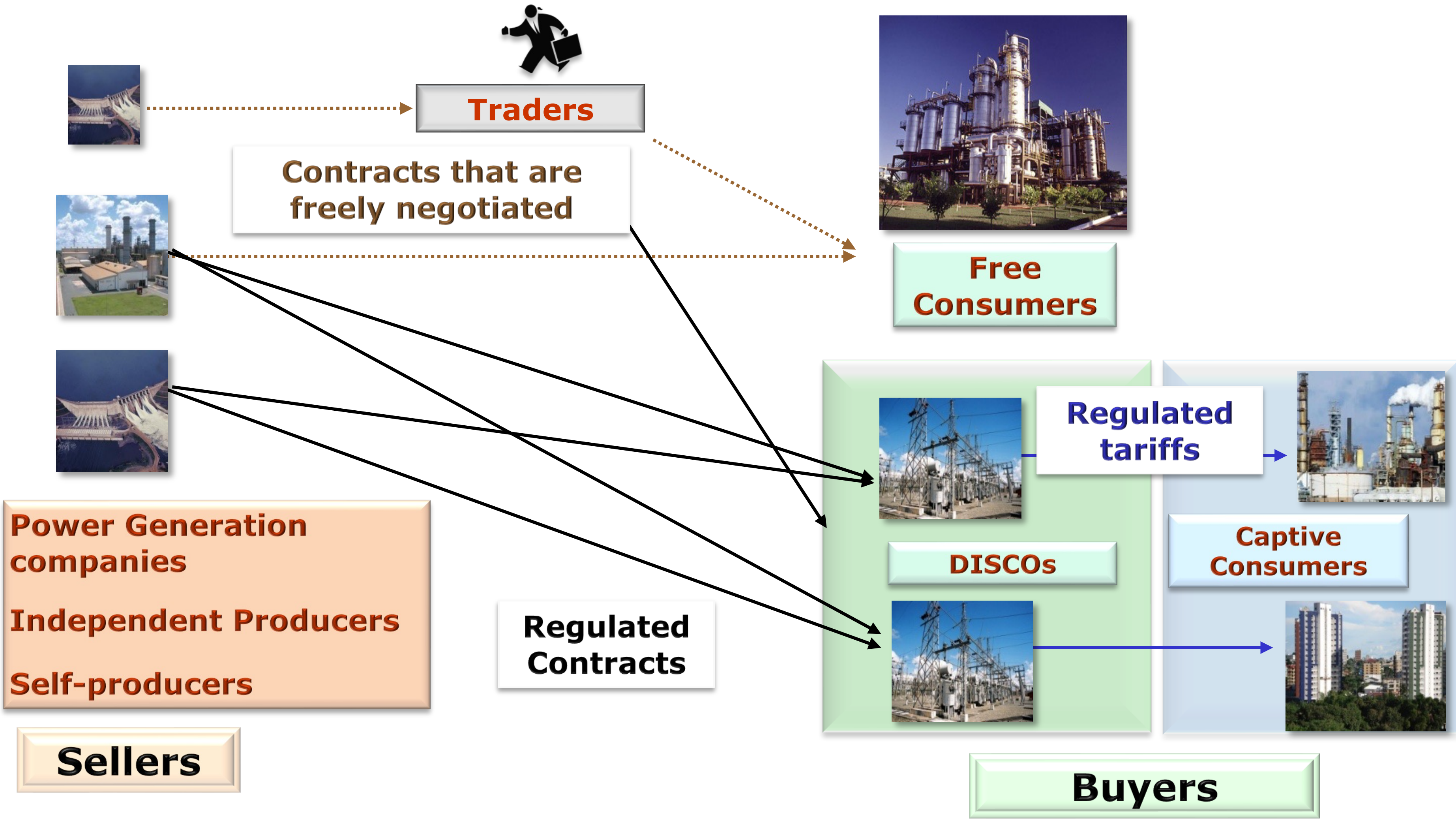
Contracts established in long-term auctions

Free Trading Environment (ACL)

- **Free Consumers**
- **Energy Sellers**

Bilateral Contracts that are negotiated freely

Market Configuration



Regulated Market: Long-term Contracts

- **In the Regulated Market,** DISCOs (≅70% of the market) buy electricity through contracts in **long-term auctions** (backed by assured energy)
  - This process is established for different reasons (promote new investments "**new energy**", sell expired contracts "**existing energy**", **promote matrix diversification**
  - The DISCOs have to contract 100% of their future demand projections (up to five years ahead)
  - A mix of prices is formed and applied to the captive consumers (**regulated electricity tariffs**)

"**New**" vs "**Existing**" Energy in Auctions

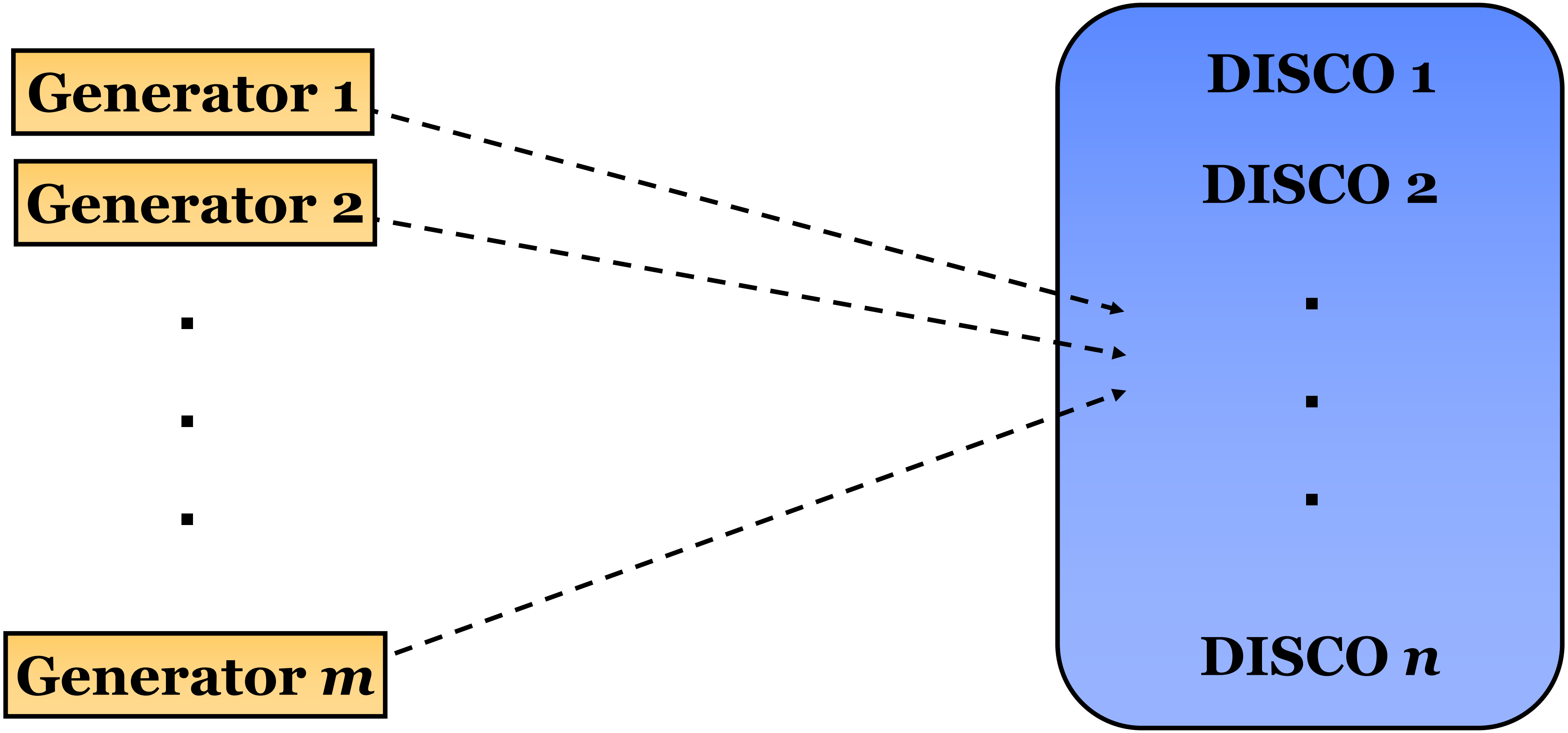
- Separate auctions for purchasing "**new energy**" (generation expansion) and "**existing**" (supply of the current market)
- Reasons for the different auctions
  - Offer contracts with **longer duration** for new generation
  - Offer contracts with **shorter duration** for existing generation
  - Management of future uncertainties by the DISCO
  - **Risk sharing** between new and existing generation, providing **flexibility in the management of energy portfolios**

Antes do Leilão: Declaração da Demanda

Before the auction each DISCO informs how much they need to hire

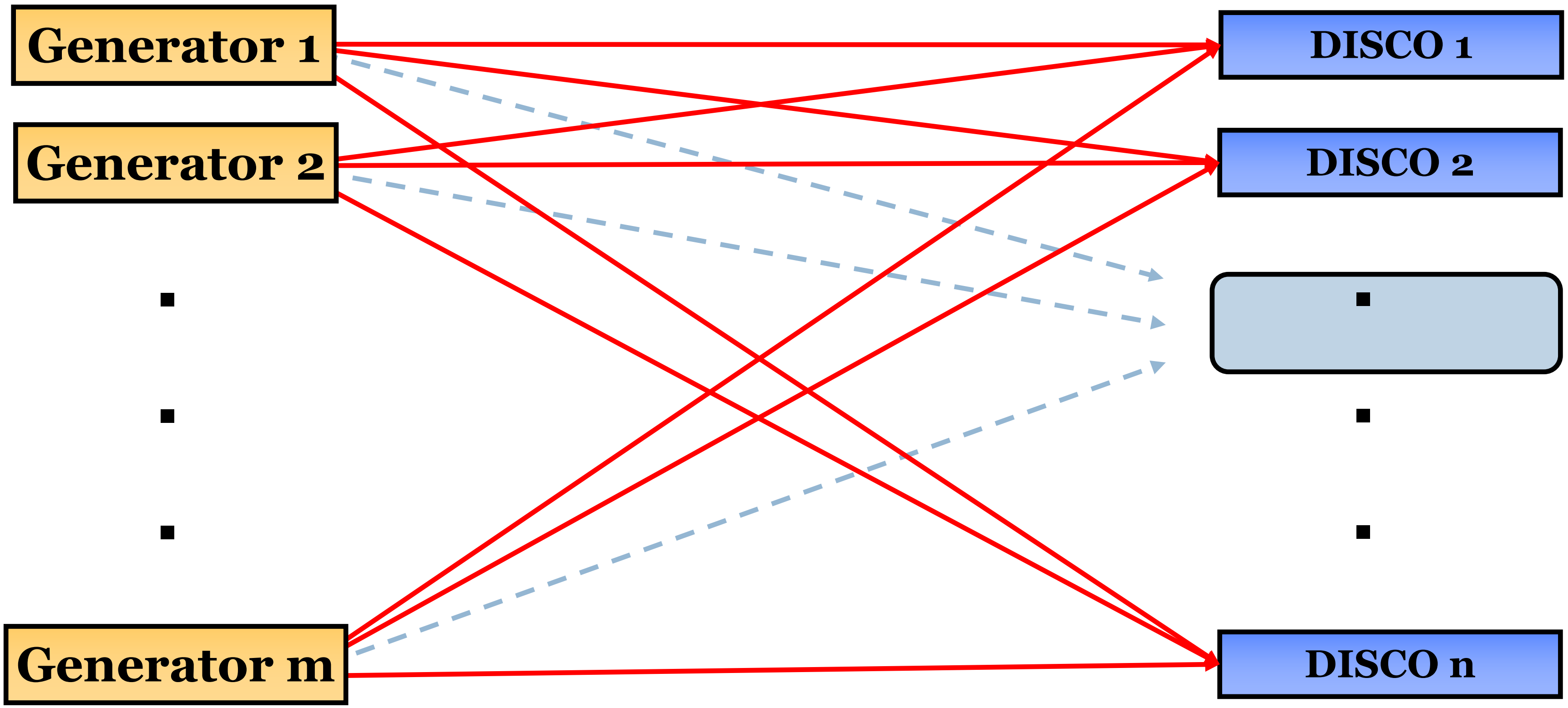
The total amount informed by each DISCO and the total amount of the pool of DISCOs is not revelead before or during the auction

During the Auction – Demand Satisfaction



An auction to hire "x" MWavg is performed
In the auction, gerators make price bids to satisfy the demand

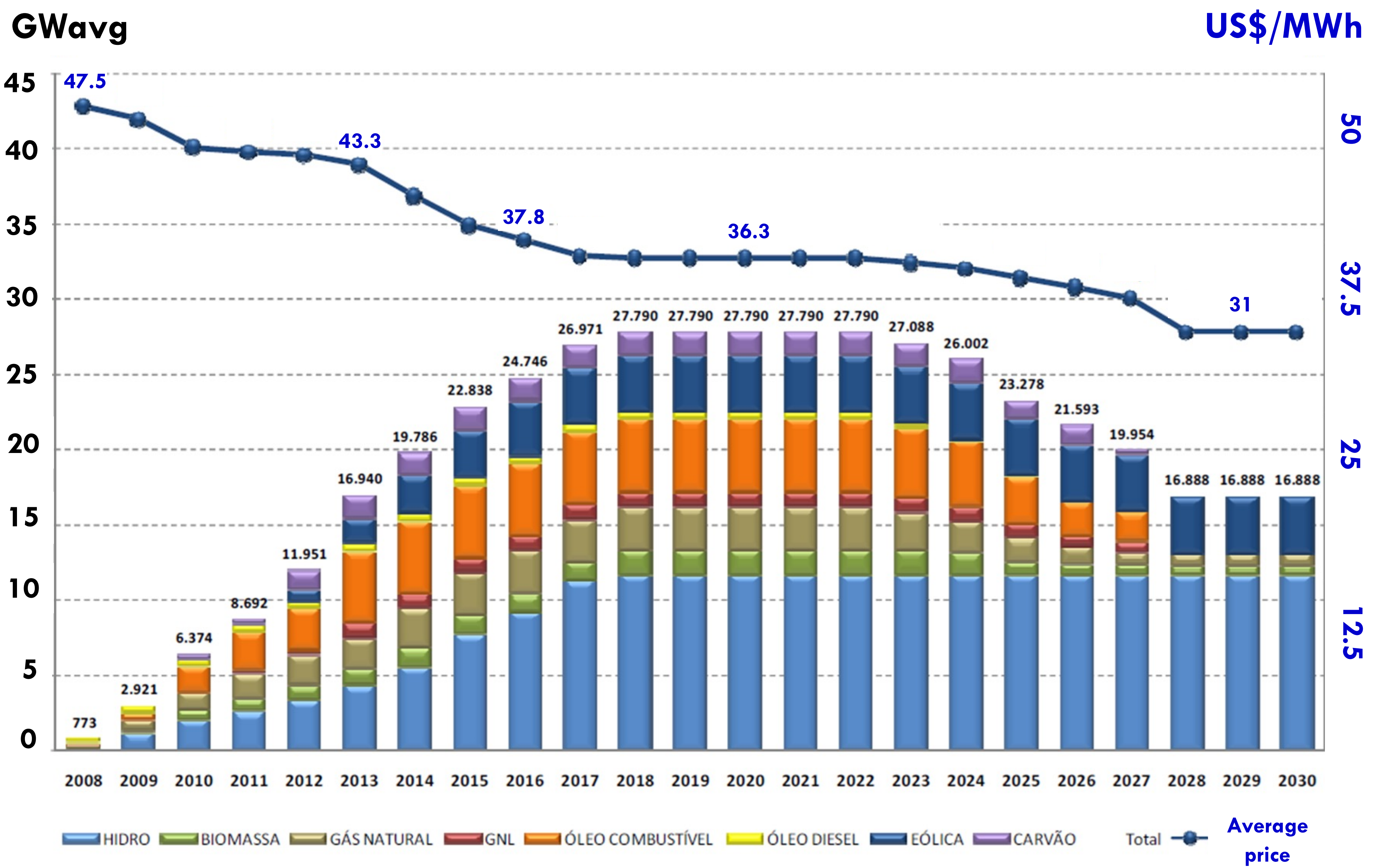
After the Auction: Bilateral Contracts



Offers most competitive in terms of price win

Then, bilateral contracts are signed in proportion to the generator offer and the DISCO demand

A Experiência do Brasil: Leilões de Energia Nova



The Brazilian Free Market

- In the Free Market (ACL), the participants can choose their supplier
- Agents attempt to manage their portfolio
  - **Minimize costs** or **maximize profits**
  - Reduce exposition to future risks
- The consumer has to **manage energy usage**

Be constant aware of

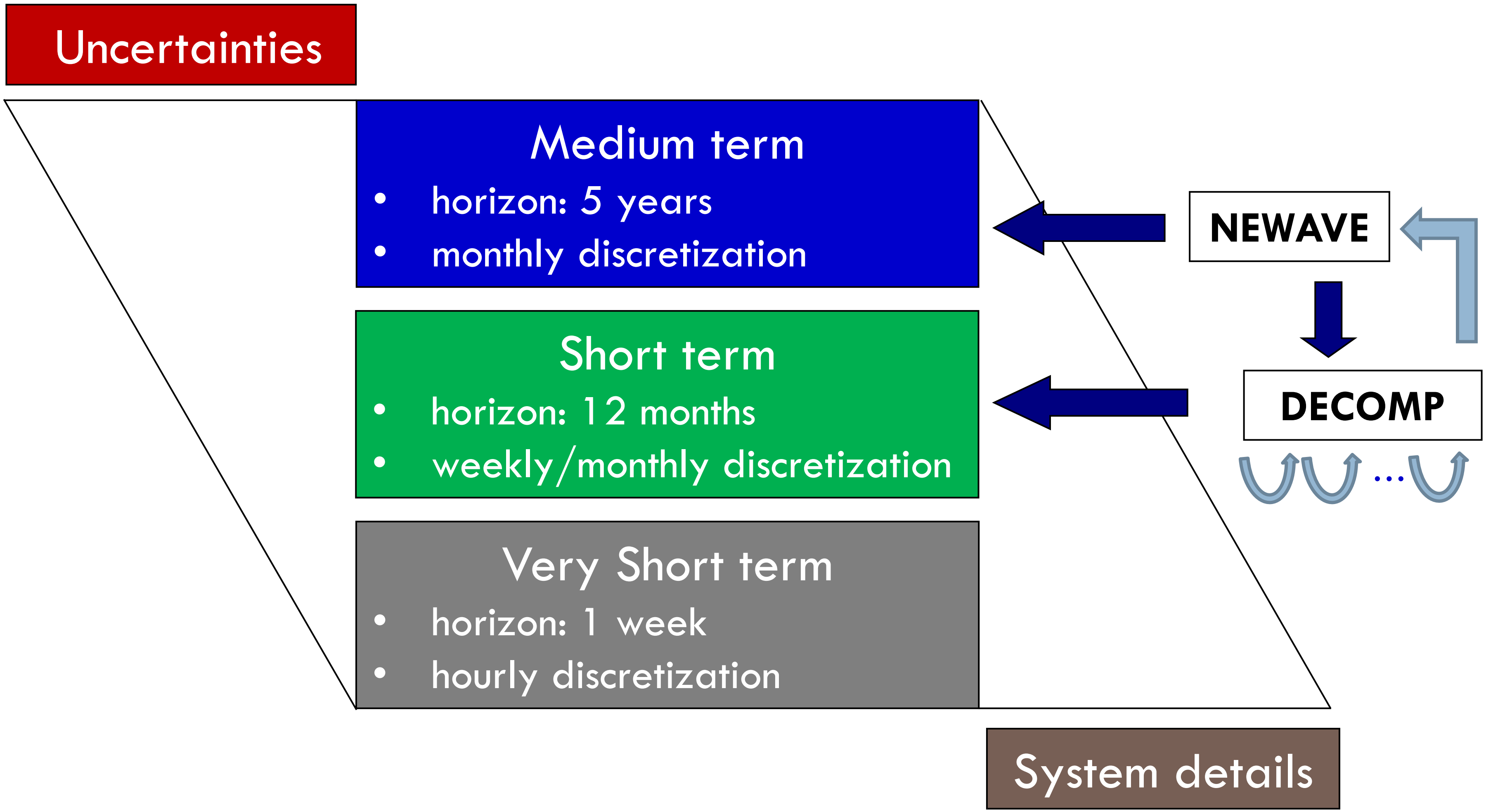
Market movements | **Rules alteration**

Pricing in the Brazilian Free Market

- The **electricity price in the Free market** is based on results obtained by HTCP optimization models (**NEWAVE e DECOMP**)
- **Methodology** based on "**Tight Pool**"
- Instead of seeking for an equilibrium between supply and demand, the **price is based on** the locational marginal prices **(LMPs)** from the **HTCP optimization**
- Where the goal is to **minimize the total expected operational costs** to satisfy the system demand during the planning horizon

How to find LMPs in a HTCP?

Operational Planning Structure

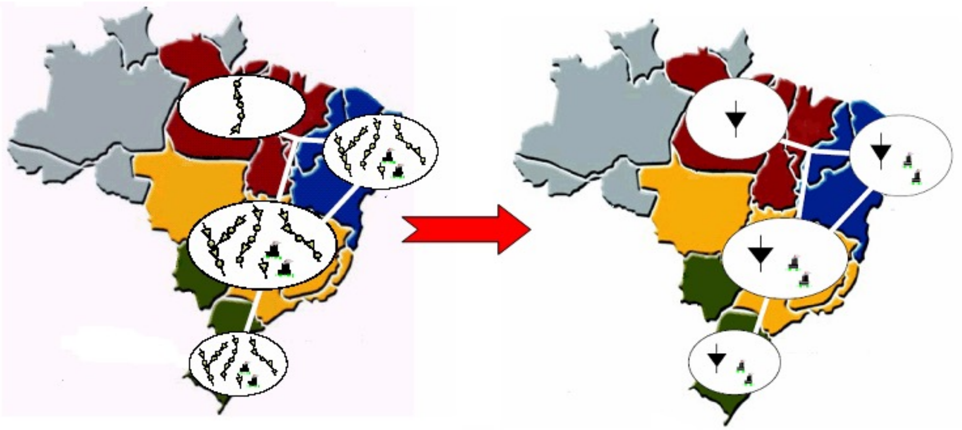


NEWAVE Model

- Used since 1999 in the Brazilian power sector
- **Optimizes the dispatches** of all the power plants (>30MW) from the SIN
- Used **in HTCP** considering **five year horizons** with monthly discretization
- **SDDP** – Stochastic Dual Dynamic Programming
- Determine the Operational policies for the power plants

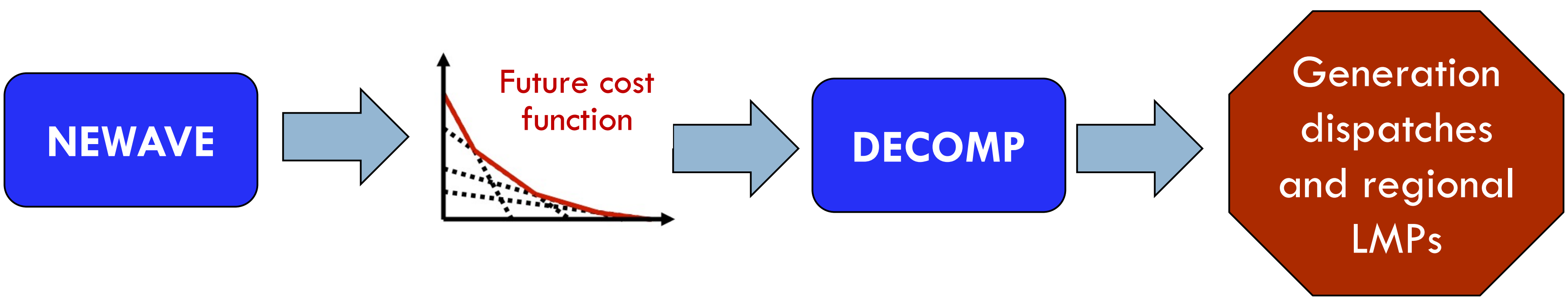
Dimensionality Reduction:

Aggregated Reservoir Representation

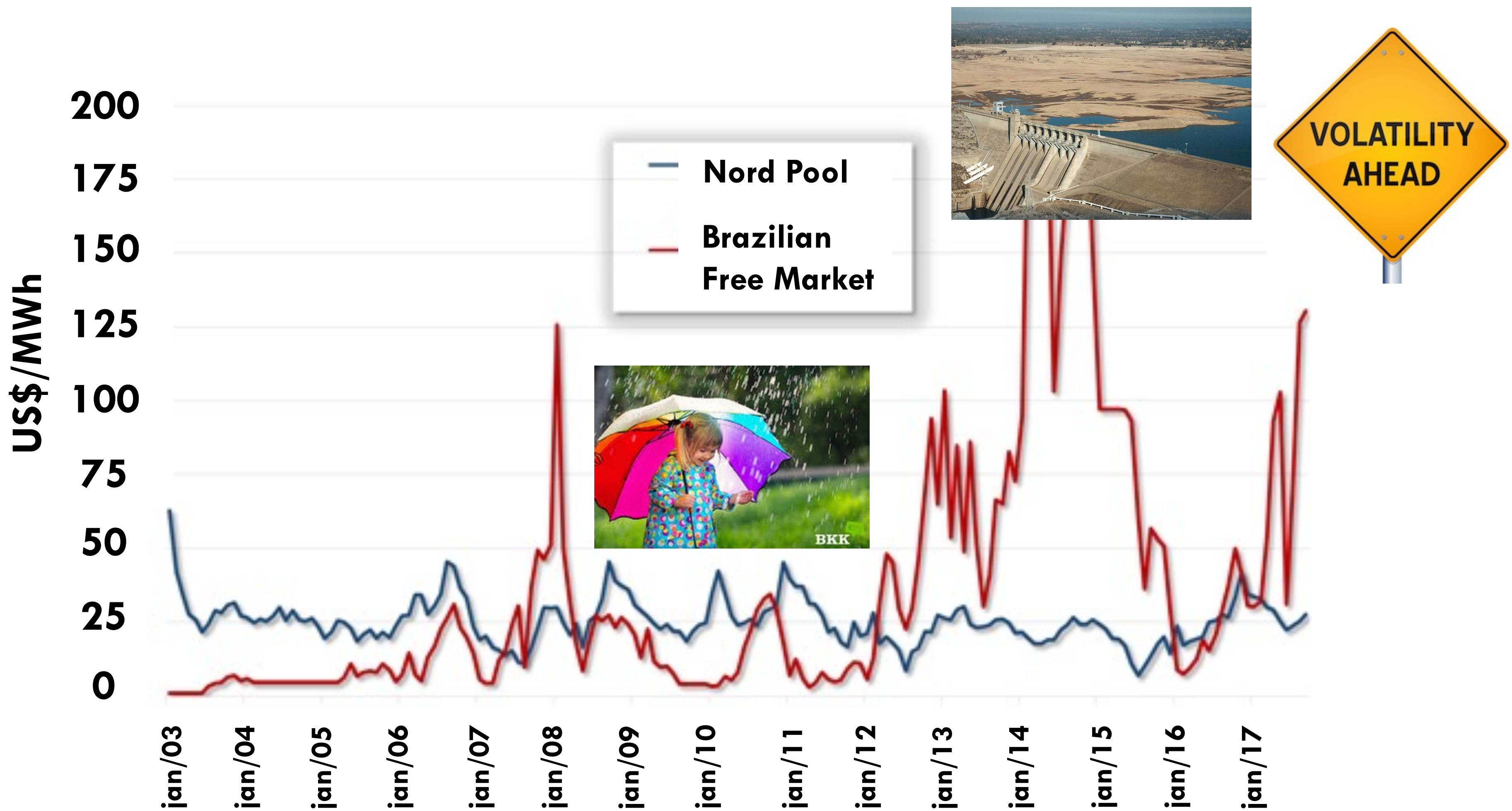


DECOMP Model

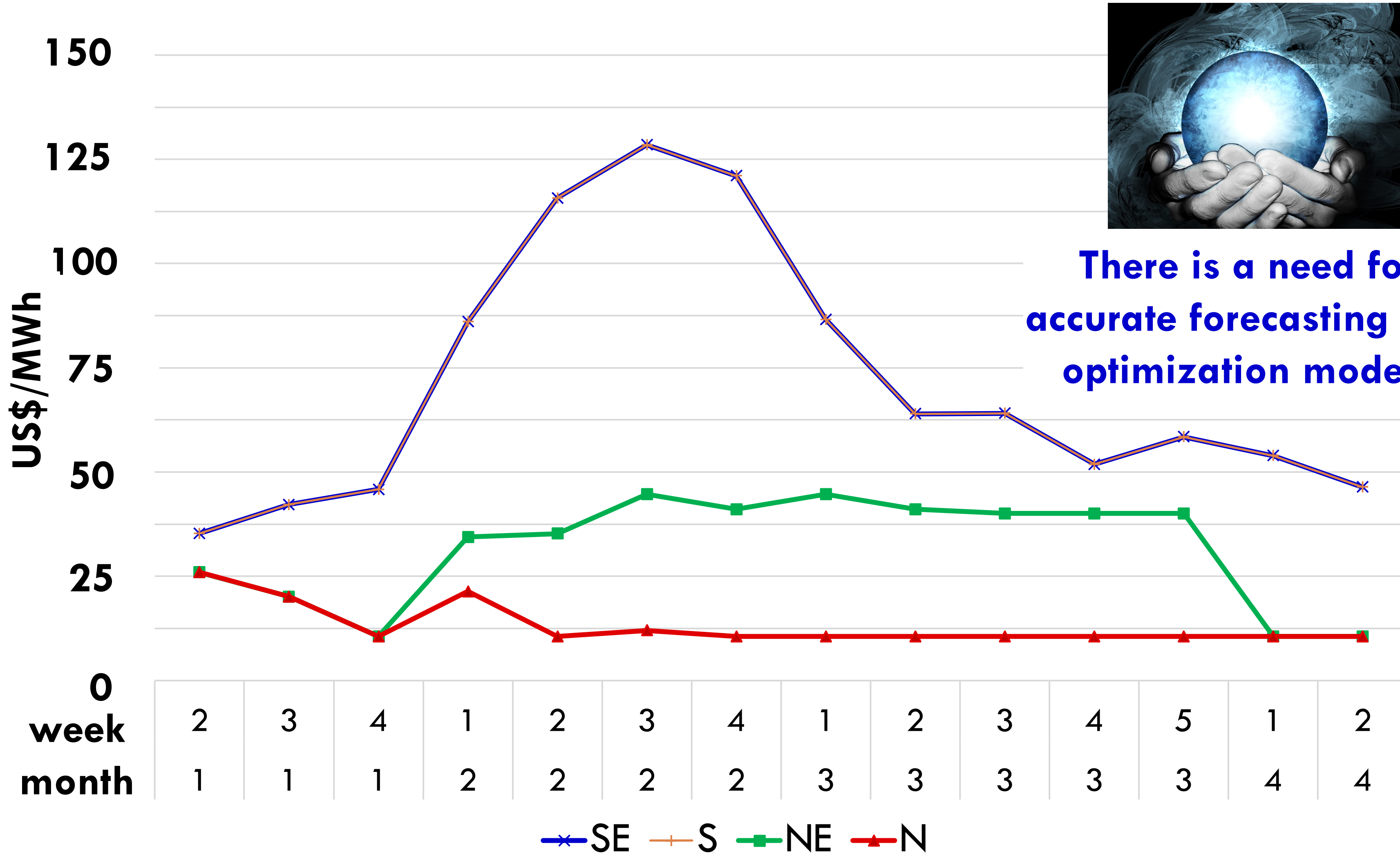
- Determine the **short term operation** of the power plants
- Representation of **individual plants** with their associated features
- Defines the **locational marginal prices** for each week
- The goal is to minimize the total operational costs to satisfy demand
- Subjected to **generation** and **transmission** operational constraints
- One year horizon with weekly and monthly discretization



Brazilian Free Market vs Nord Pool - Prices



Free Market LMPs - 2019



There is a need for accurate forecasting and optimization models

Final Comments

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- The **Brazilian electric power sector** was discussed
- The structure of the electricity market was presented
- The HTCP is key in the definition of operational strategies that minimizes operational costs
- The HTCP is used to define prices in the Free Market
- **Analytics** and **Decision-making** techniques are key to support system analysts when defining operations strategies, managing portfolios and planning systems resources

THANK YOU !

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