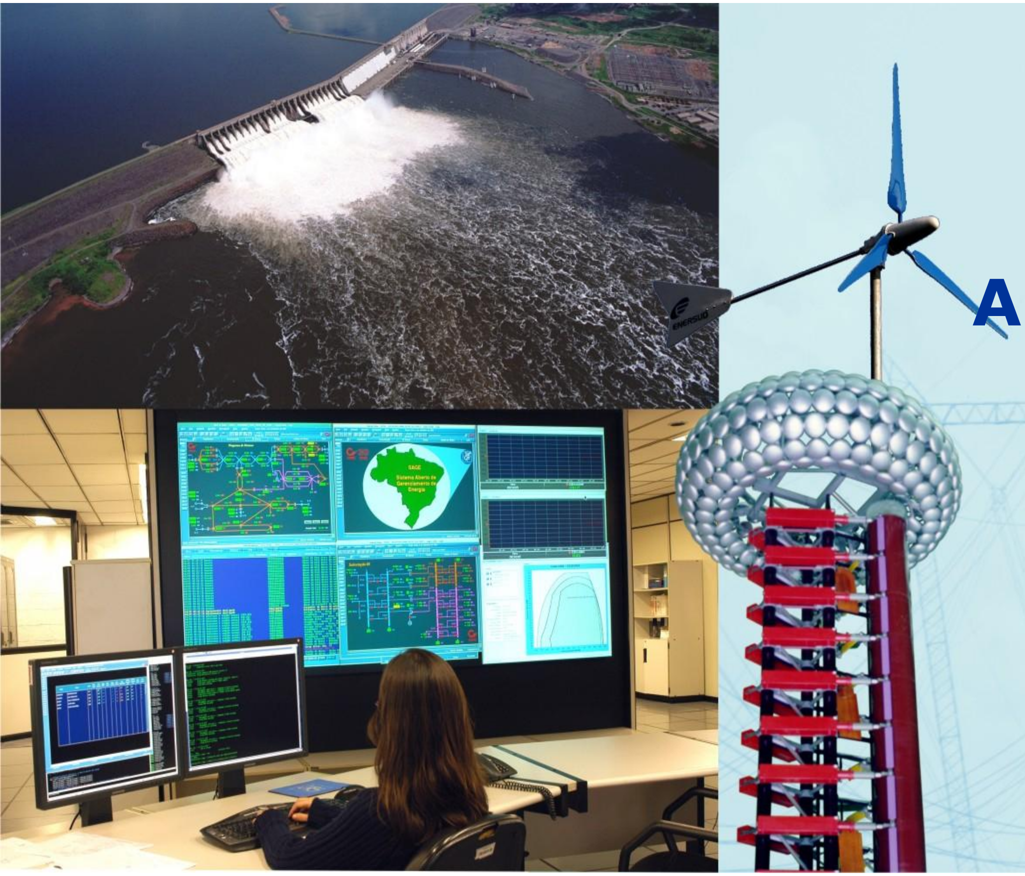
Brazilian Electric Energy Research Center - CEPEL



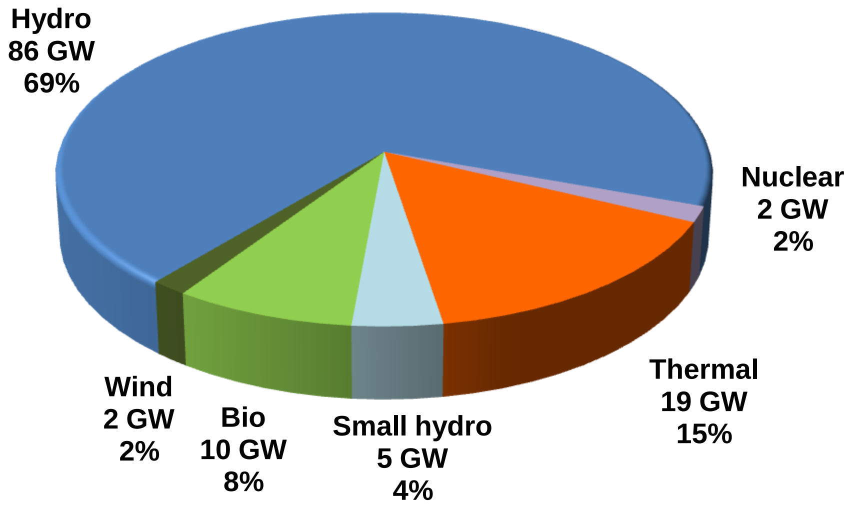
Stochastic Optimization as a Supporting Tool to Analyze the Performance of the Brazilian Hydrothermal Interconnect System under Critical Inflow Scenarios

Maria Elvira Piñeiro Maceira

DEA – Energy Optimization and Environment Department

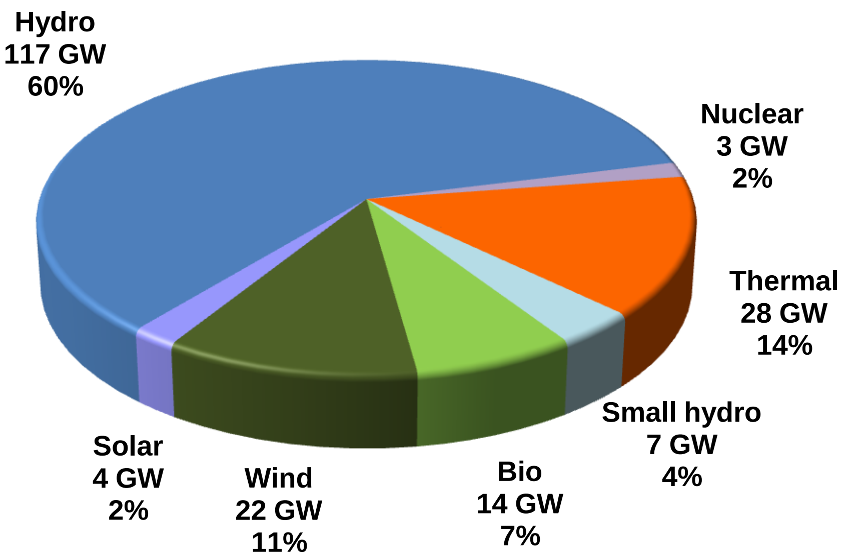
Brazilian Interconnected System Main Features

Gen. Cap. Mix
December/2013
124,796 MW



Added Capacity 2014-2023
71,087 MW

Gen. Cap. Mix
December/2023
195.883 MW



Note1: Includes import
Note2: Excludes self-production

Source: MME/EPE - PDE 2023

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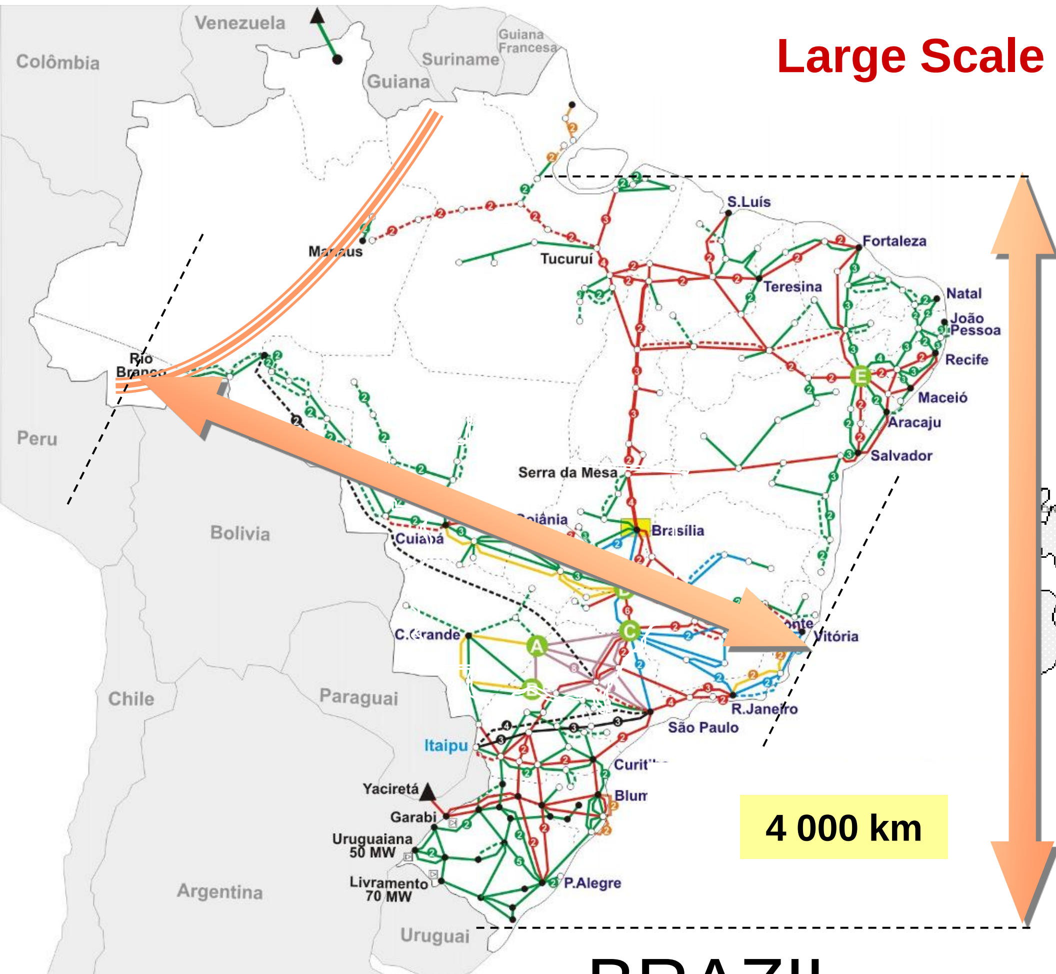
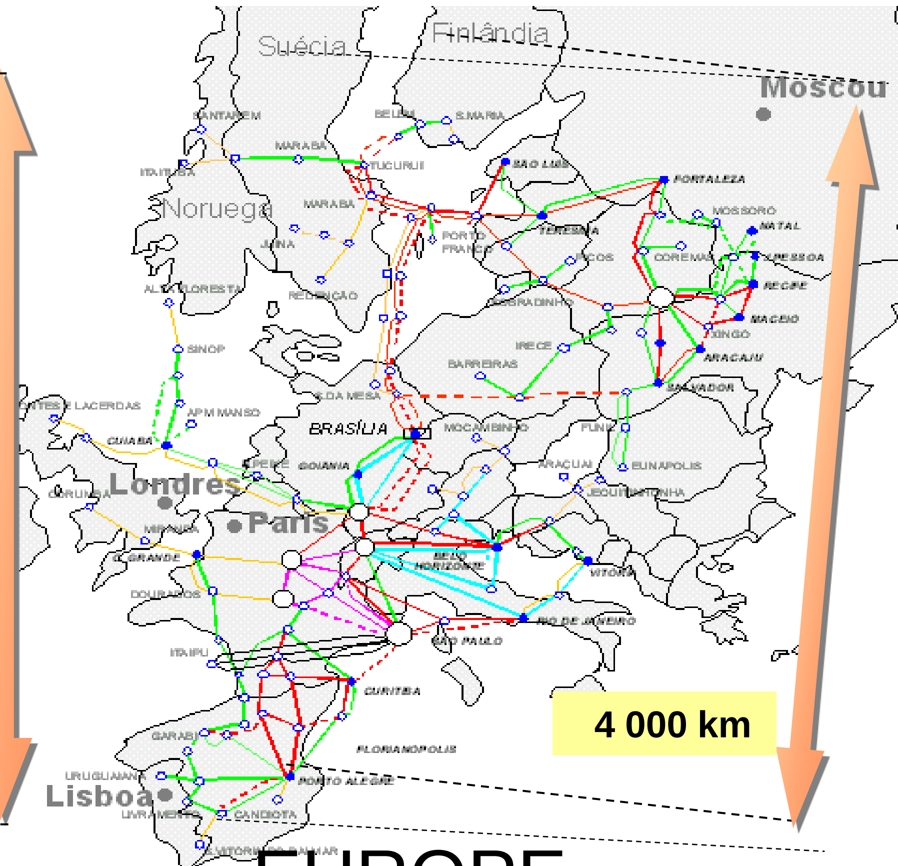
Continental Dimension

Large Scale Power System



BRAZIL



EUROPE

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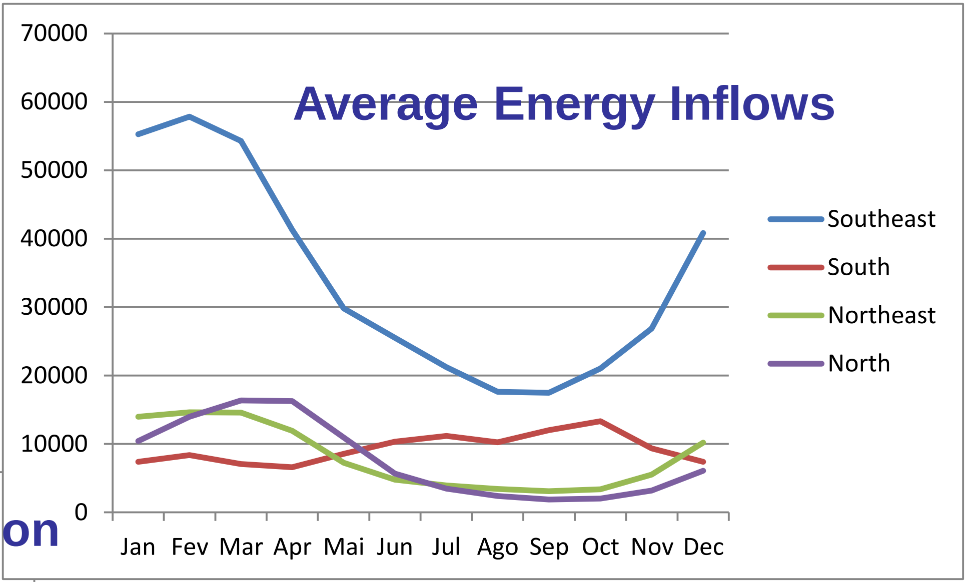
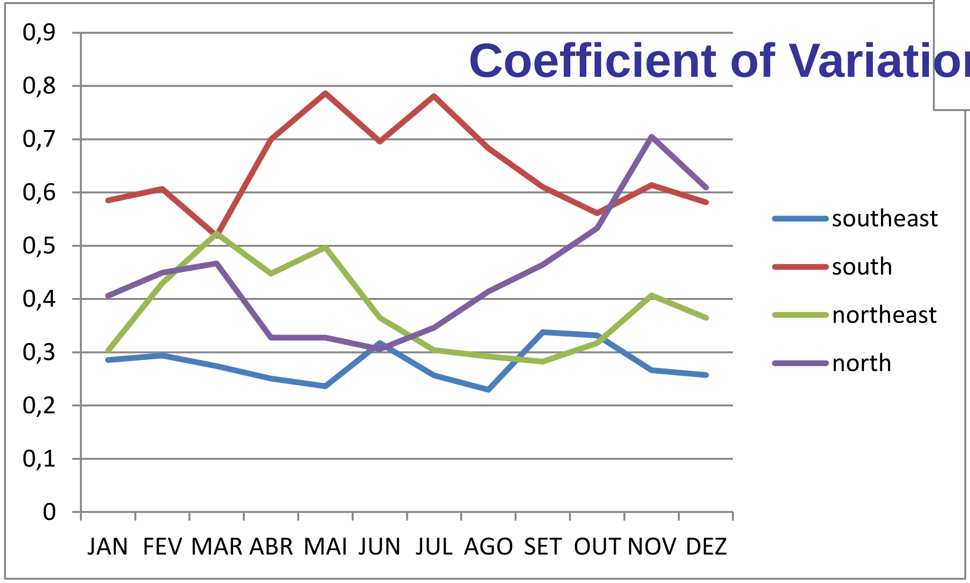
Hydrothermal Coordination Problem

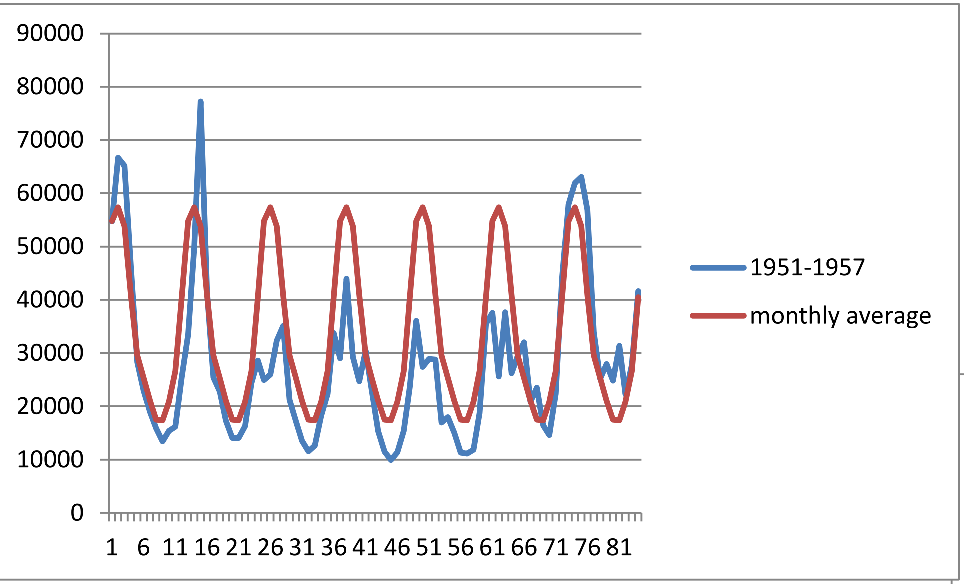
- Coupled in time and space
- Future water inflows have a stochastic behavior
- Inflows vary greatly in different seasons and even from year to year



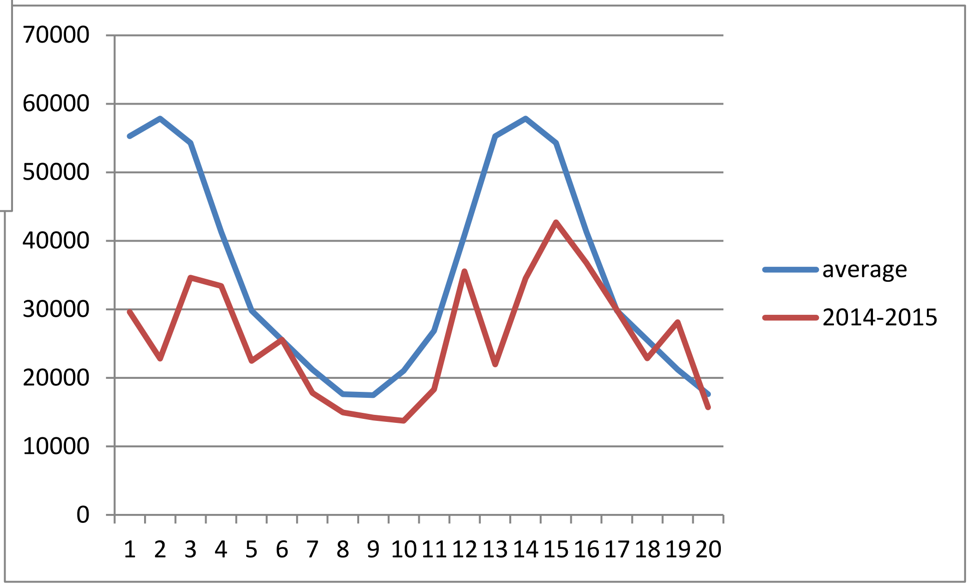


Hydrothermal Coordination Problem

- **The historical inflow records present multi-year dry periods**



Southeast



Brazilian Hydropower System

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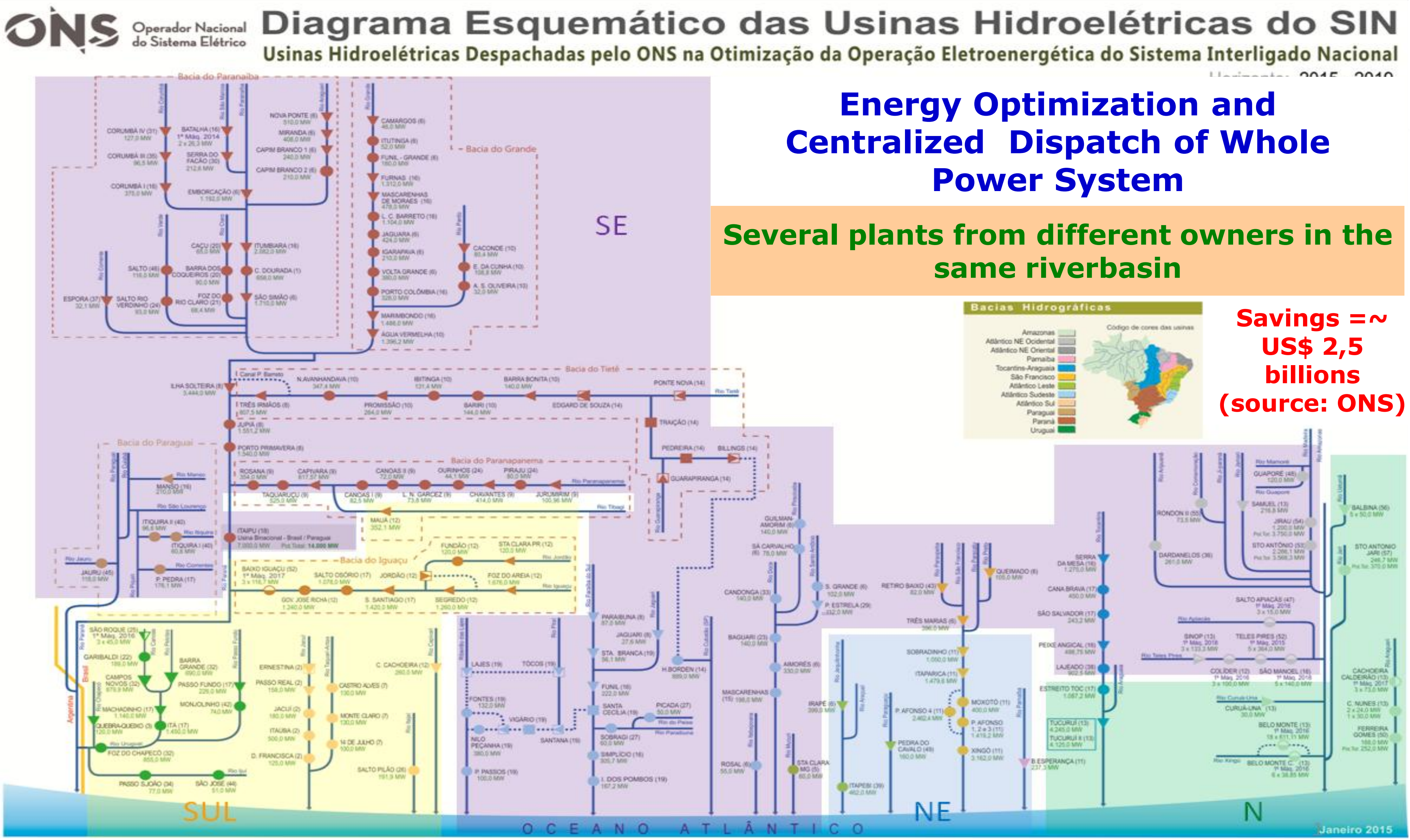
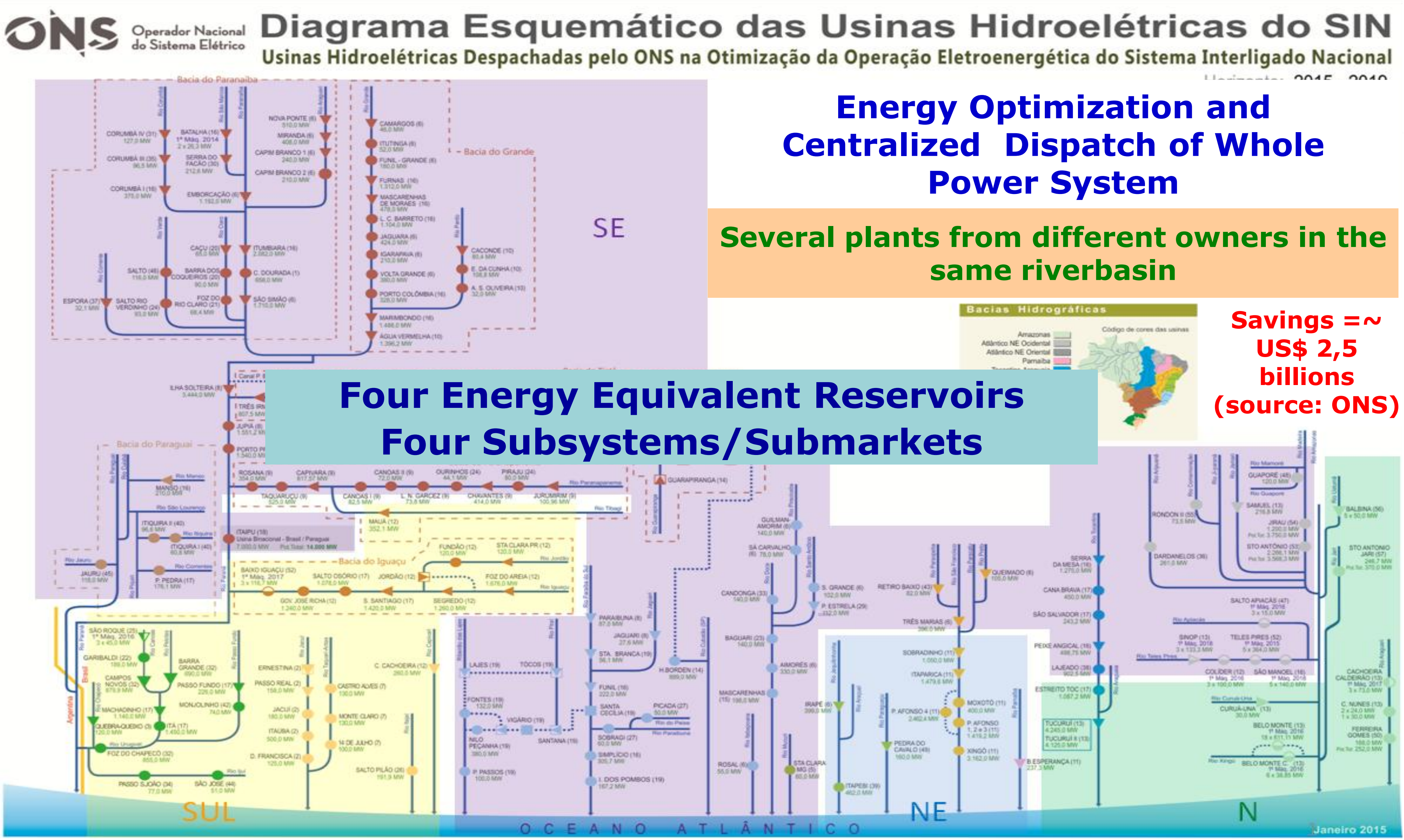


Energy Optimization and Centralized Dispatch of Whole Power System

Several plants from different owners in the same riverbasin

Savings =~ US$ 2,5 billions (source: ONS)

Brazilian Hydropower System



Energy Optimization and Centralized Dispatch of Whole Power System

Several plants from different owners in the same riverbasin

Savings =~ US$ 2,5 billions (source: ONS)

Four Energy Equivalent Reservoirs
Four Subsystems/Submarkets

Brazilian Hydropower System

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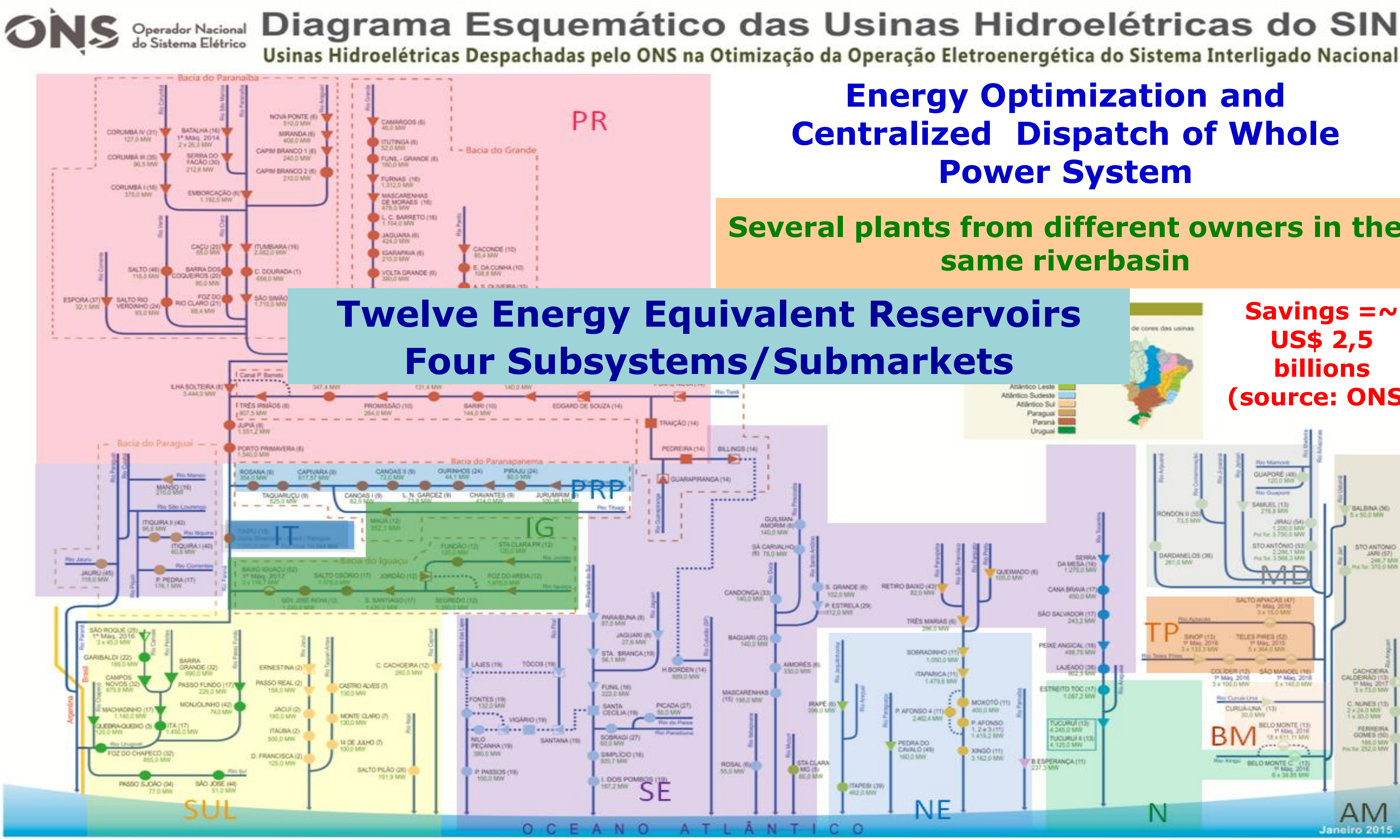


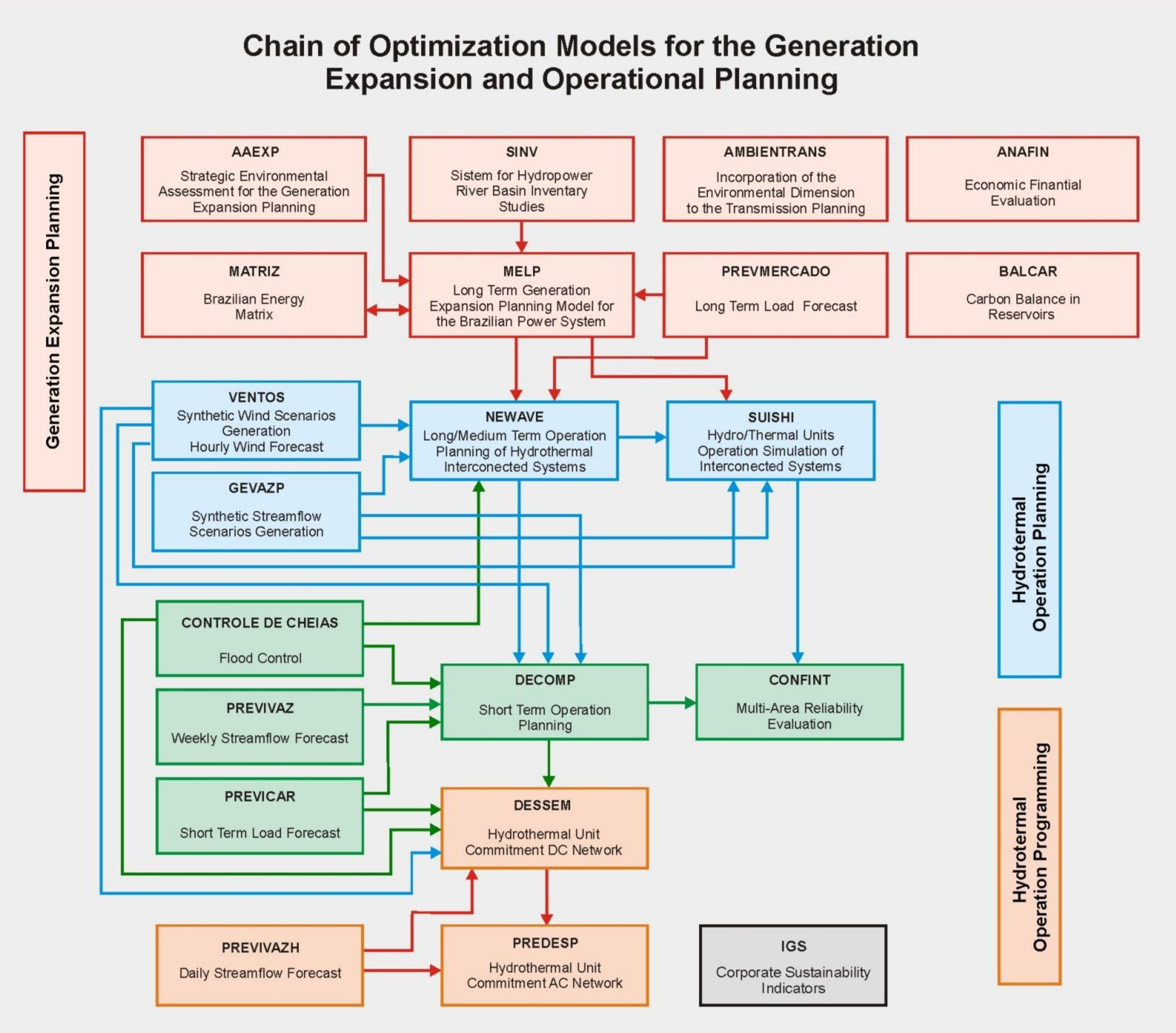
Energy Optimization and Centralized Dispatch of Whole Power System

Several plants from different owners in the same riverbasin

Twelve Energy Equivalent Reservoirs
Four Subsystems/Submarkets

Savings =~ US$ 2,5 billions (source: ONS)

CEPEL´s Chain of Optimization Models for the Generation Expansion and Operational Planning of the Brazilian System



Energy Optimization and Centralized Dispatch of the Whole Interconnected Hydrothermal System:

20% More Energy Production

Need of capturing synergies in planning and operation stages

September/ 2015

CEPEL´s Chain of Optimization Models for the Generation Expansion and Operational Planning of the Brazilian System

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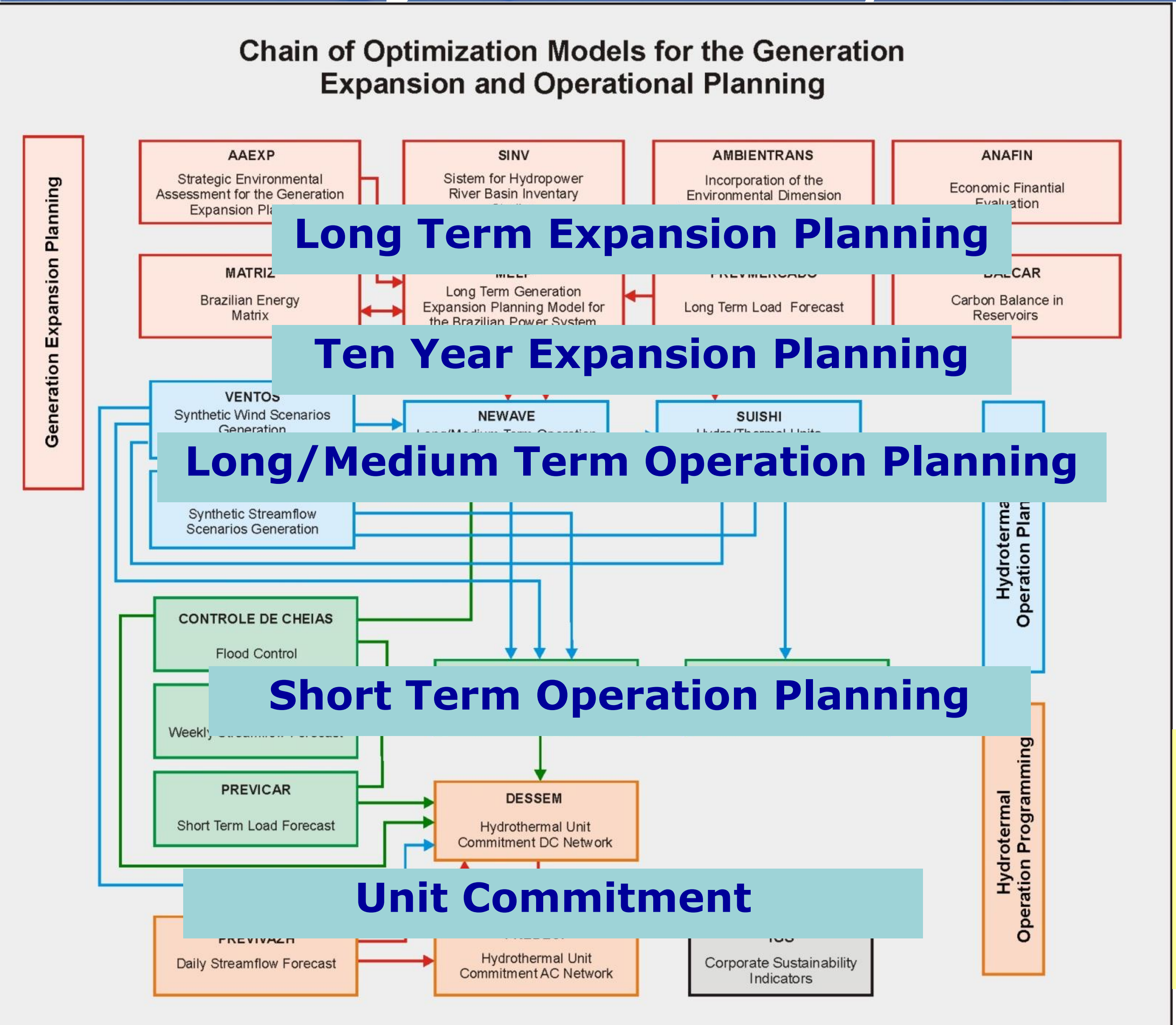


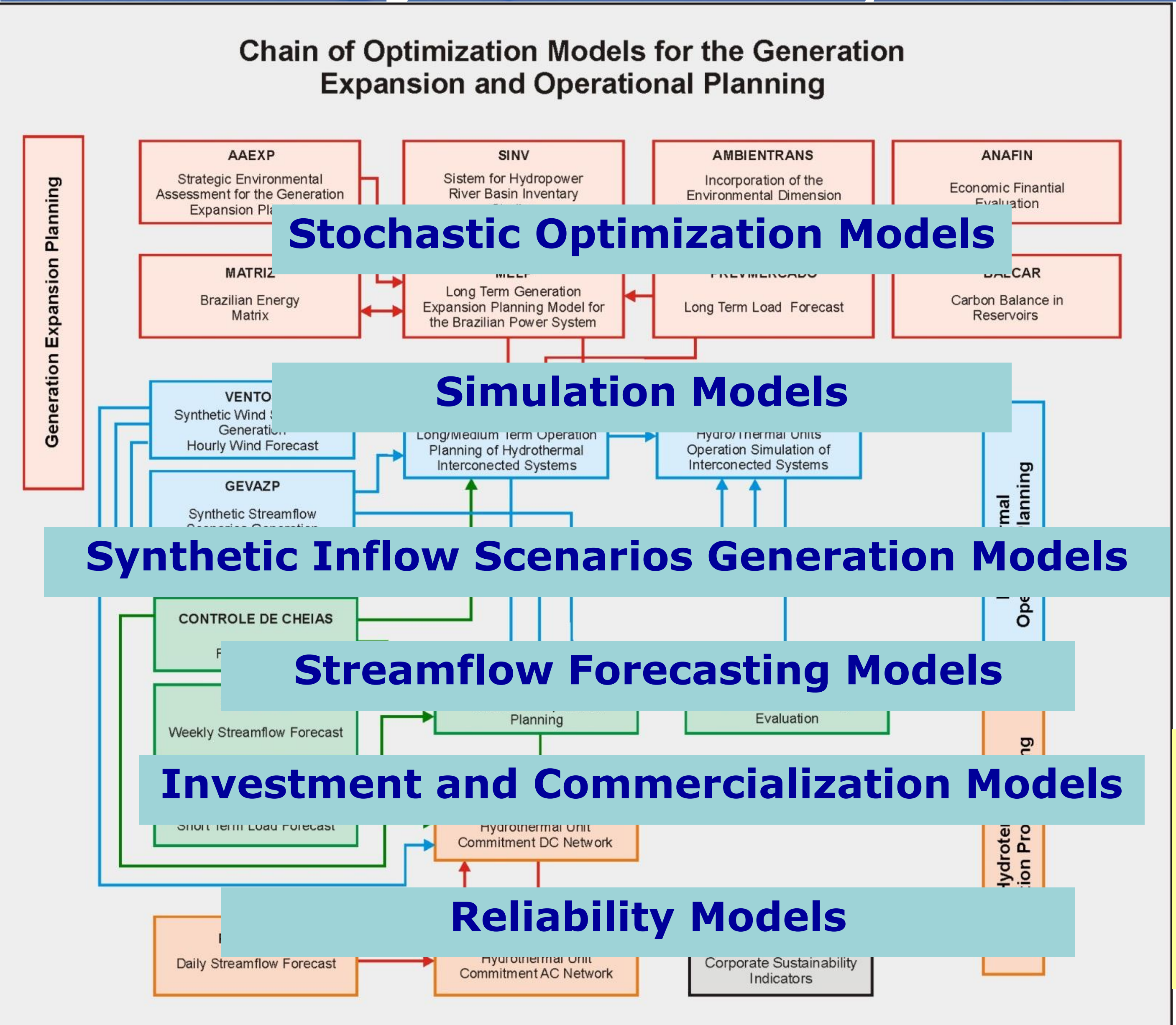
Energy Optimization and Centralized Dispatch of the Whole Interconnected Hydrothermal System:

20% More Energy Production

Need of capturing synergies in planning and operation stages

CEPEL´s Chain of Optimization Models for the Generation Expansion and Operational Planning of the Brazilian System

Eletrobras
Cepel



Energy Optimization and Centralized Dispatch of the Whole Interconnected Hydrothermal System:

20% More Energy Production

Need of capturing synergies in planning and operation stages

Monthly Operation Planning - PMO

First Module – Energy Equivalent Reservoir

The aggregation technique, known as equivalent reservoir representation, is based on the estimation of the energy produced by the complete depletion of the system reservoirs for a given set of initial storage

The equivalent reservoir model is a composite representation for the multireservoir hydroelectric power system: one reservoir, which receives, stores and releases potential energy

One equivalent reservoir can present <u>hydraulic coupling</u> with another equivalent reservoir downstream

One or more energy equivalent reservoir attend the demand of a subsystem/submarket

The Brazilian system is currently represented by 4 energy equivalent reservoirs in Operation Studies (9, in Jan/2016) and by 11 in Expansion Studies

Third Module - Hydrothermal Operation Strategy

Stochastic dual dynamic programming (Benders decomposition) is used to solve the multi-stage stochastic linear programming problem (the operation dispatch problem)

OBJECTIVE FUNCTION

$$\min \; \underset{\omega}{E} \underbrace{\left[\left(\sum_{t=1}^{T} \left(\sum_{i=1}^{NT} c(gt_i^{t,\omega}) + \sum_{s=1}^{NS} Defc_i^{t,\omega} \right) \right) \right]}_{\text{Thermal generation and deficit costs}}$$

until Aug/2013

Third Module - Hydrothermal Operation Strategy

Since Sep/2013 a risk averse approach is considered optimization

The so called CVaR (Conditional Value at Risk)

Weight for Expected Value minimization

2 STAGE MODEL

$$\min_{x_1}\left[\begin{array}{l} c_1x_1 + \boxed{(1-\lambda)}\; E\left[\min\limits_{x_2 \,\middle|\, A_2x_2(\omega_2)=b_2(\omega_2)-E_1x_1} c_2x_2\right] \\ \quad + \boxed{(\lambda)}\; CVar_{\alpha}\left[\min\limits_{x_2 \,\middle|\, A_2x_2(\omega_2)=b_2(\omega_2)-E_1x_1} c_2x_2\right]\end{array}\right]$$

Risk level

$\lambda = 0{,}25$
$\alpha = 0{,}5$

Weight for CVaR minimization

A direct CVaR approach to SDDP was proposed and implemented in NEWAVE model

Third Module - Hydrothermal Operation Strategy

CONSTRAINTS

$$\sum_{i\in H_j} gh_i^{t,\omega} + \sum_{i\in T_j} gt_i^{t,\omega} \pm \sum_{i\in Int_j} Int^{t,\omega} + Defc_j^t = D_j^t, \quad \forall t,\omega,j$$

Demand supply - submarket

$$earm_s^t = earm_s^{t-1} - gh_s^{t,\omega} + \underbrace{\xi_s^{t,\omega} \,\Big|\, (\xi_{s,\,p-1,\dots P}^{t-p,\omega}, \zeta),}_{} \quad \forall t,\omega,j$$

Energy conservation – REE

Par-P model
Selective Sampling

$$gh_s^{t,\omega} = f(earm_j^{t,\omega})$$

hydro generation limits - REE

...

storage limits - REE

Lower bounds on total outflow – equivalent energy reservoir (REE)

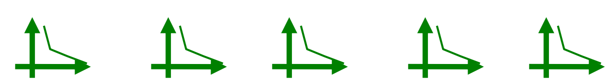
thermal generation limits - submarket

Energy interchanges limits among submarkets

Benders cuts

$$\varphi_t(x_{t-1}) \ge \sum_{\omega=1,\dots K} p_\omega \left[z_{t,\omega*} + \left\langle \frac{\partial z_{t,\omega*}}{\partial x_{t-1}}(\hat{x}_{t-1,s*}), x_{t-1} - \hat{x}_{t-1,s*} \right\rangle \right]$$

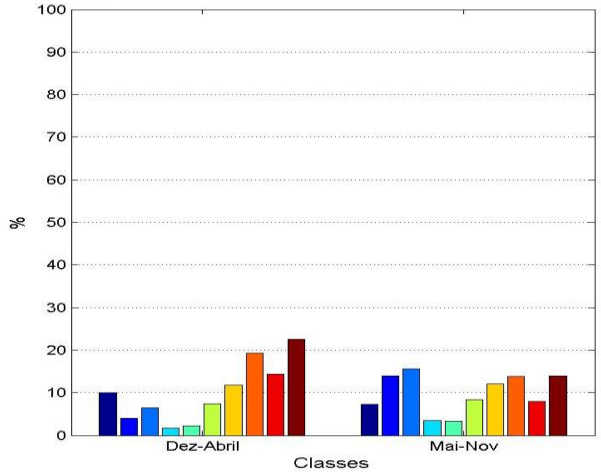
OUTPUT:



Operation Policy

Forth Module - system operation simulation by using multivariate inflows scenarios

- **Calculation of system performance probabilistic indices**
  - **energy deficit risks**
  - **expected energy not supplied**
  - **expected operation marginal costs**
  - **Probability distributions of operating costs, marginal costs, flow interchanges, hydro generation, thermal generation etc**
- **Energy inflows scenarios**
  - **multivariate**
    - **spatial and time correlation**
  - **synthetic streamflows generation**
    - **2,000 scenarios**
    - **PAR(p) model**
      - **Conditioned or not to the recent trend**
  - **historical record sequences**



Second Module – Energy Inflows Scenarios Generation GEVAZP model

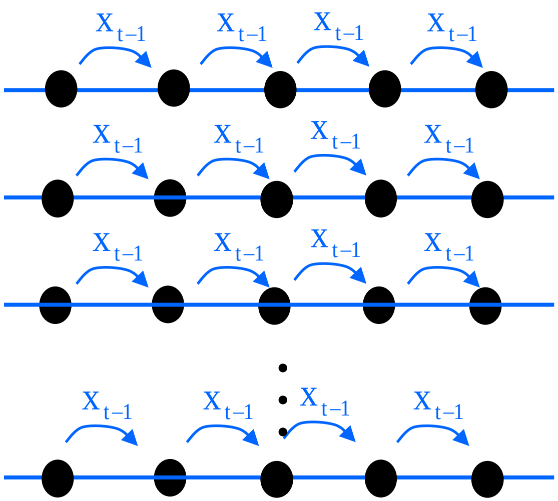
Forward pass

Scenario 1

Scenario 2

Scenario 3

Scenario S << K^T



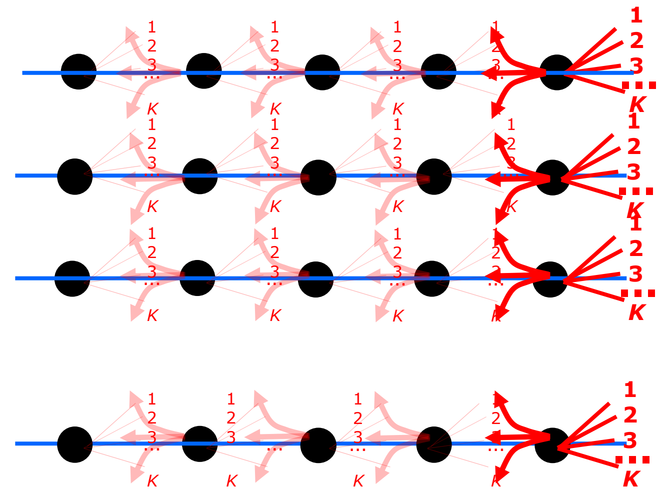
Backward pass

Scenario 1

Scenario 2

Scenario 3

Scenario S << K^T

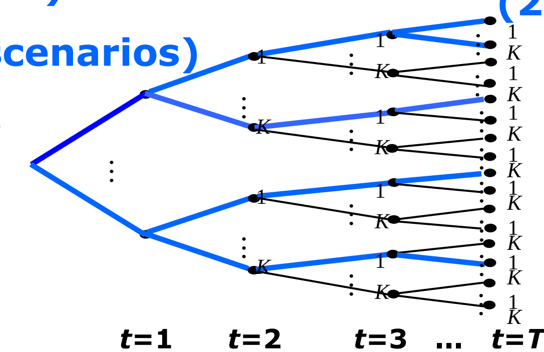


Optimal policy construction (200 scenarios)

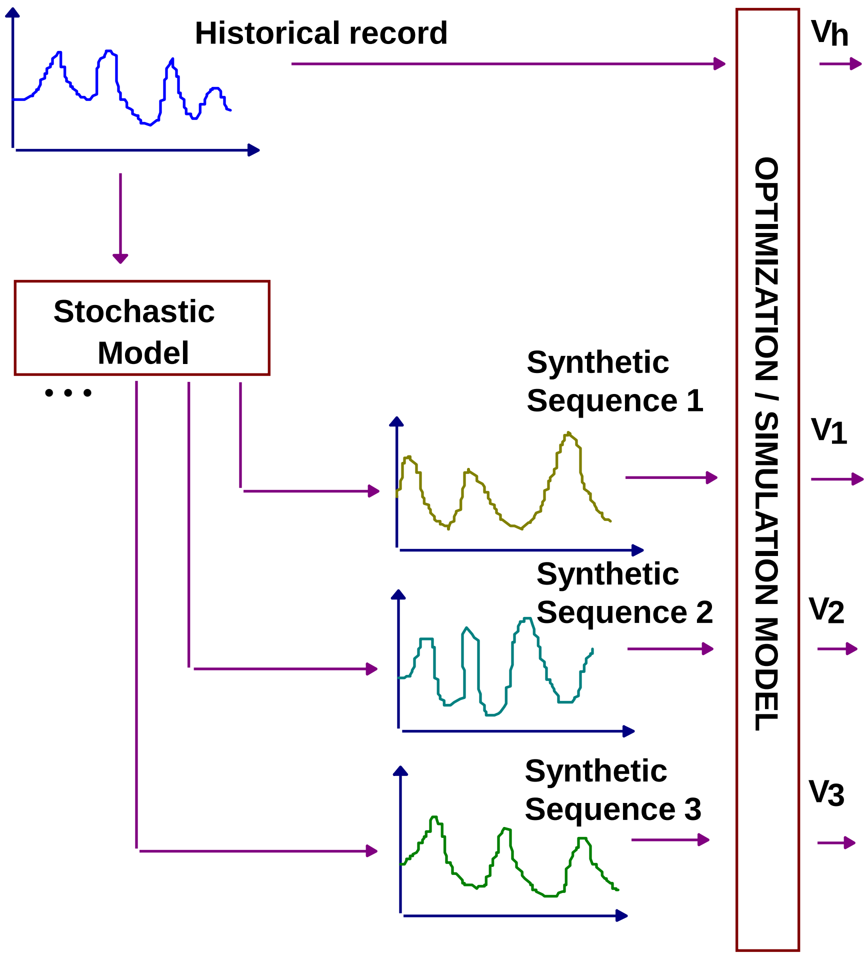
(20 scenarios)

Final simulation operation policy (2000 scenarios)

Conditioned or not to recent past inflows



Energy Inflows/ Streamflows



Choose a stochastic time series model that ensures resemblance between the historical and synthetic inflow sequences (streamflows or energy inflows)

***Stochastic time series model*: PAR(p)**

. the inflow at period (t) is a function of the past inflows (t-1), (t-2), ...

. the time dependence structure is seasonal

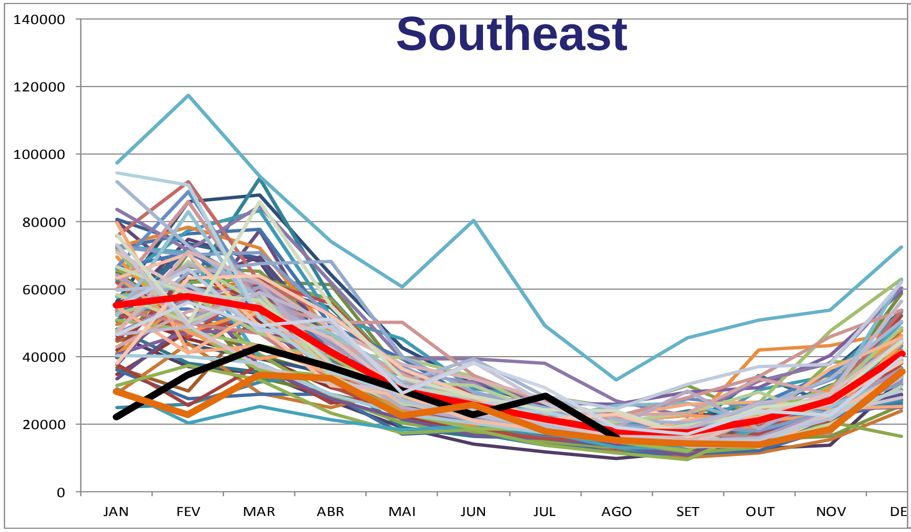
. preserves temporal and spatial correlation and considers selective sampling

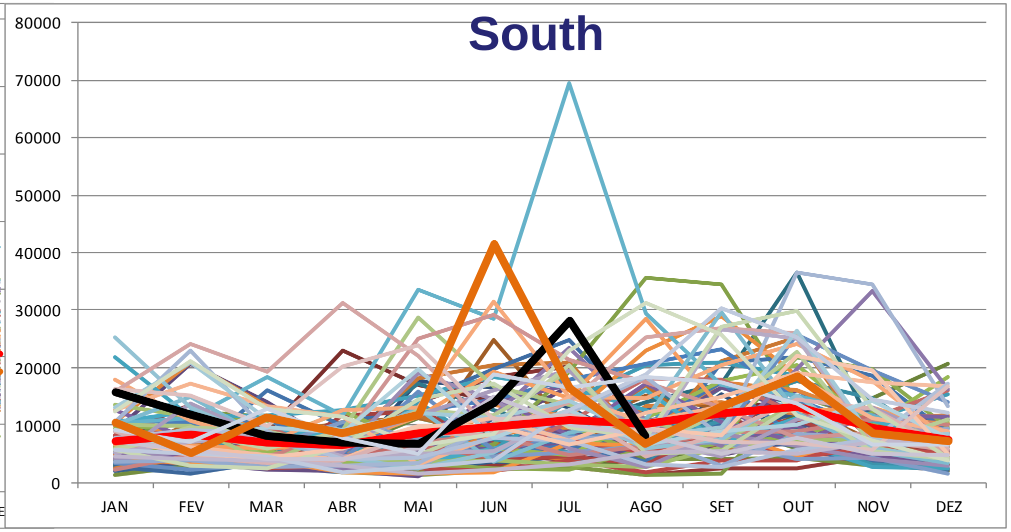
Scenarios can be conditioned to recent past inflow or each scenario can be conditioned to a different past inflow

Demand Supply Evaluation

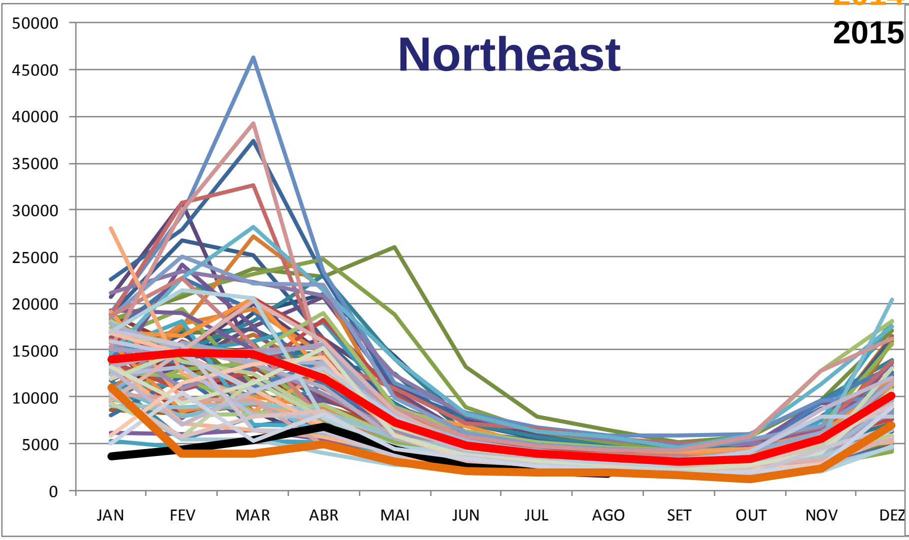
2014

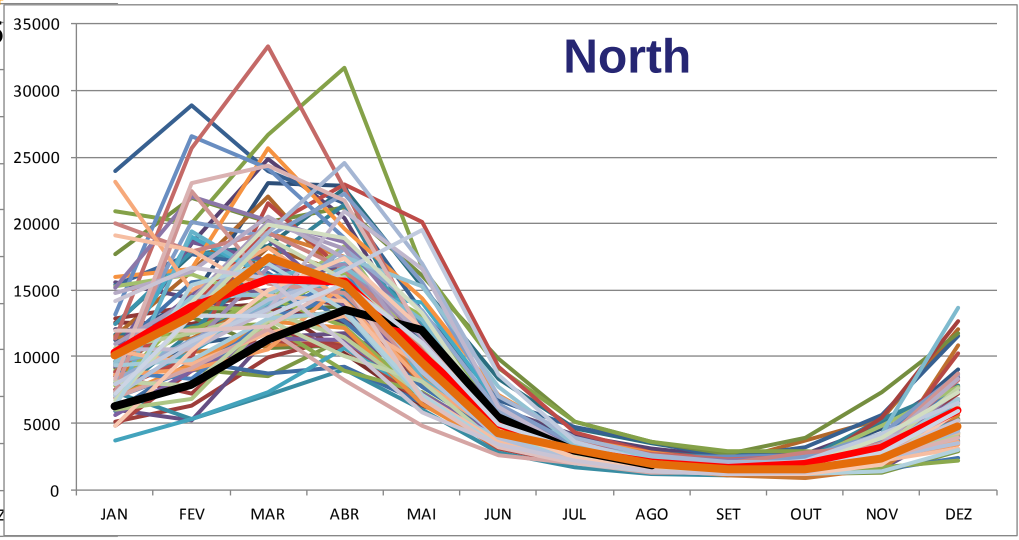
Energy Inflows - Historical Records 1931 to 2015





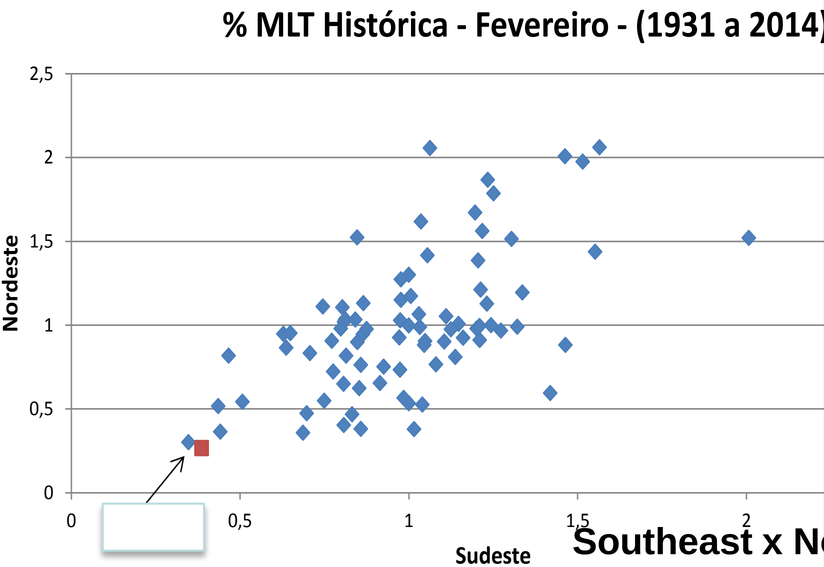
monthly average
2014
2015



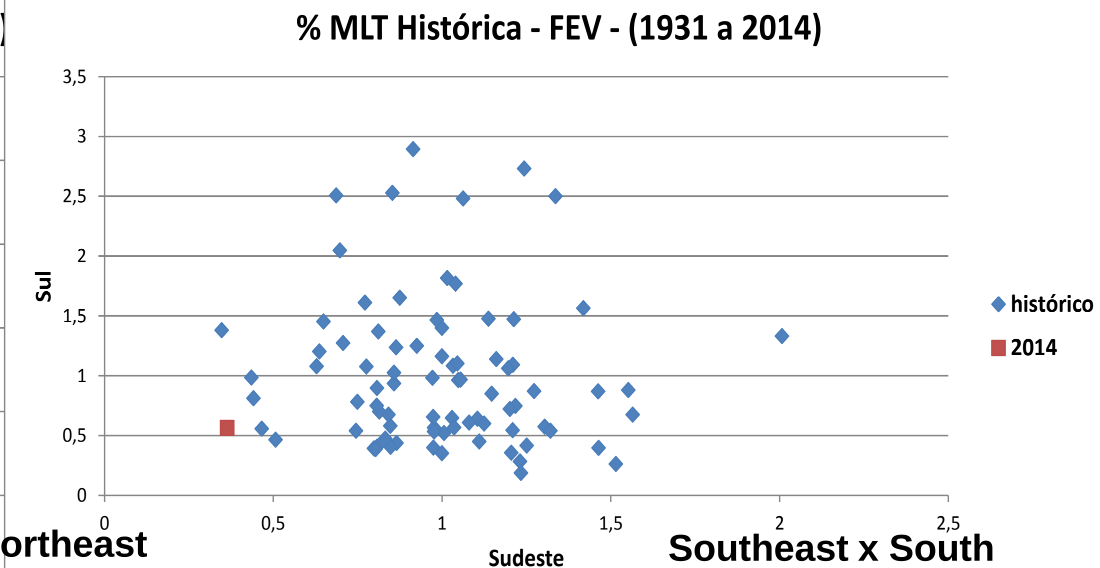


Energy Inflows – Historical Record for February/14 and January/15

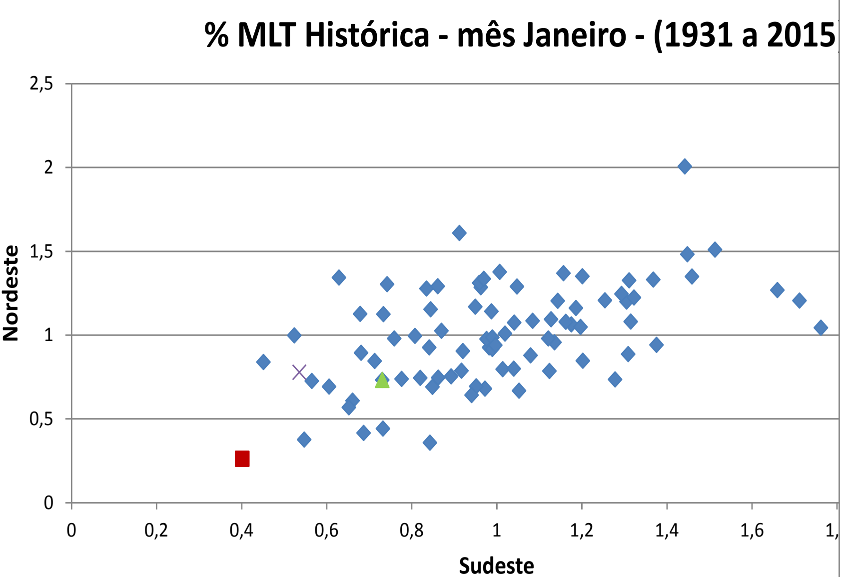
(% of Monthly Mean)

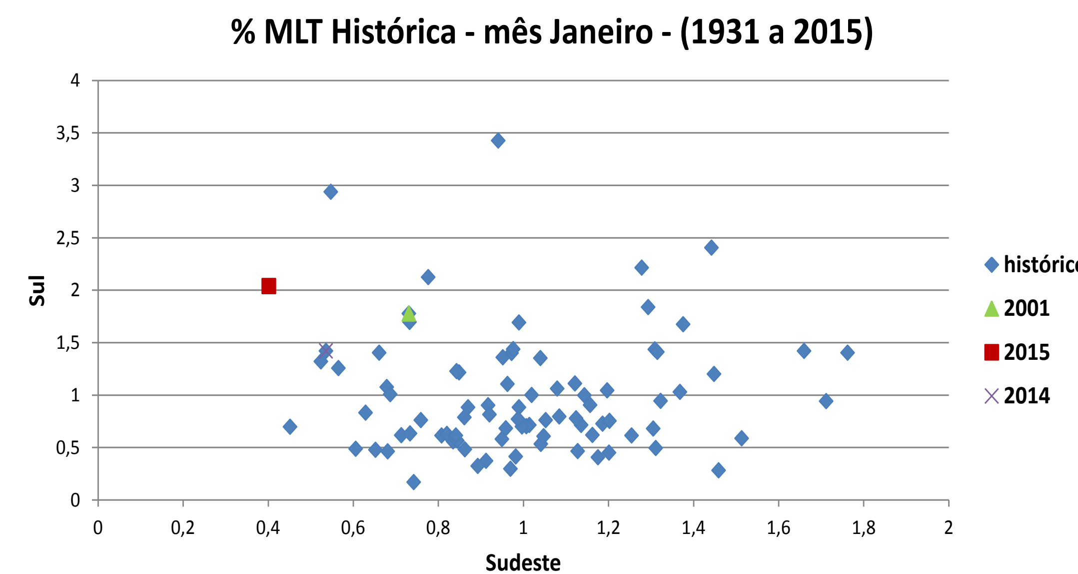


Southeast x Northeast



Southeast x South





System Performance Evaluation
Months Ahead

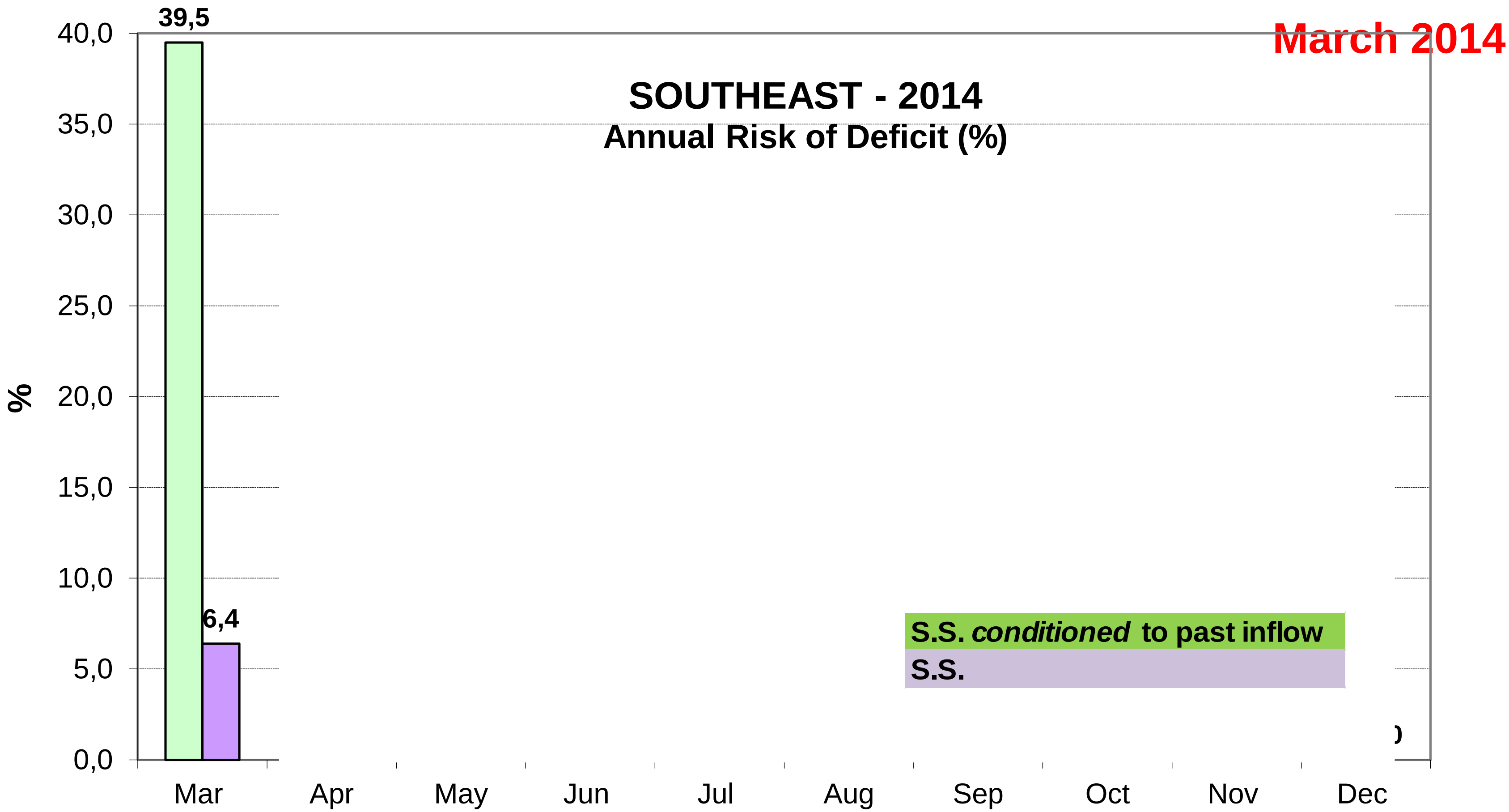
- Recognize relevant uncertainties, such as inflows to reservoirs
- Select a set of *indicators*
- Choose an *appropriate methodology* to *estimate* the indices associated to these indicators
  - Synthetic and historical inflow scenarios
  - Conditioned and "unconditioned" synthetic inflow scenarios
  - If the trend is extreme, as occurred in February 2014 or January 2015, the synthetic scenarios could present very low representation in historical record
    - It is recommended that the evaluation of system performance periods ahead is made from "unconditioned" synthetic inflow scenarios and historical scenarios

Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

Eletrobras Cepel

Indices calculated by PMOs - 2014

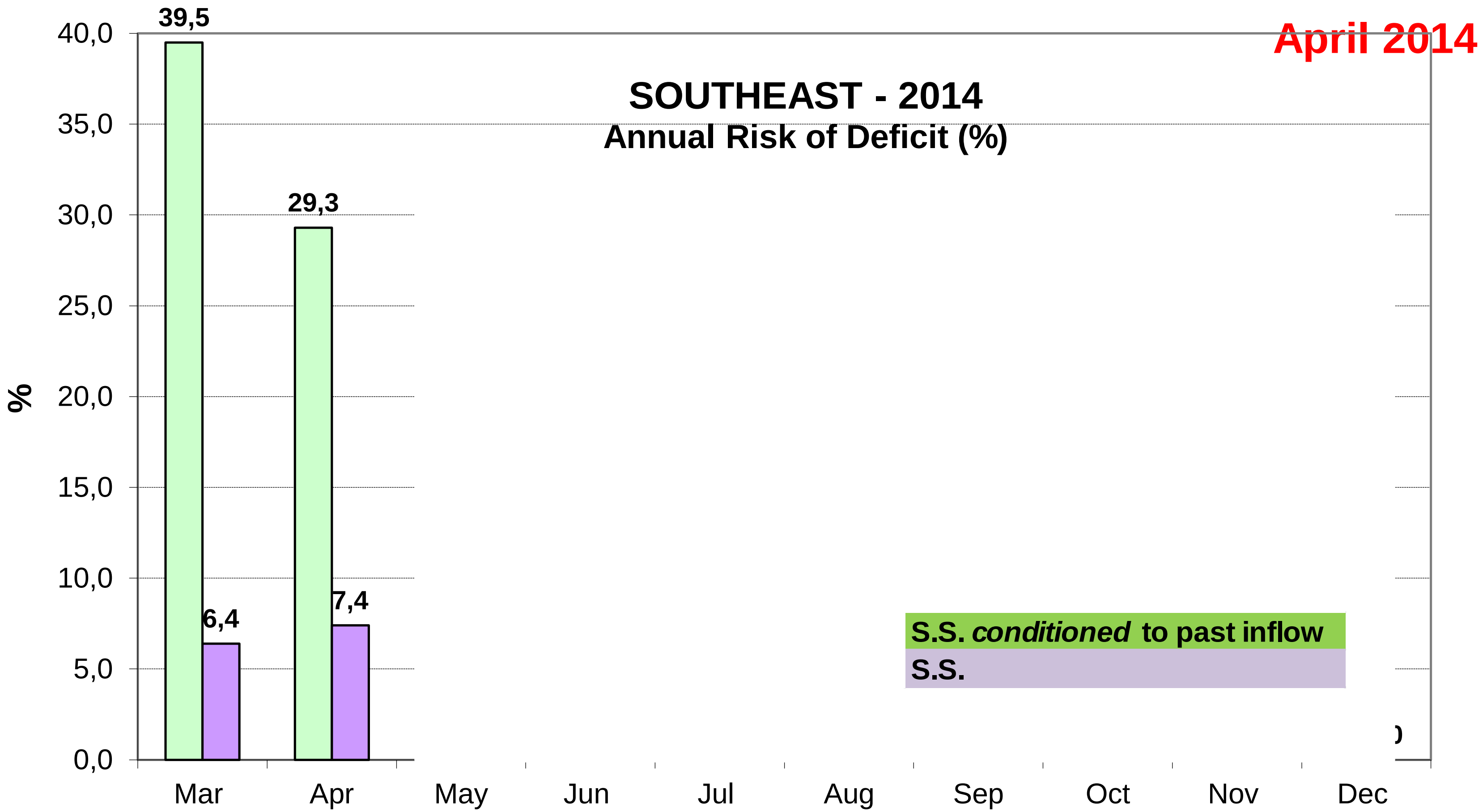
SS Wi
SS Wi



	Feb/14
E inflow	39,00%
Storage	35,40%

Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

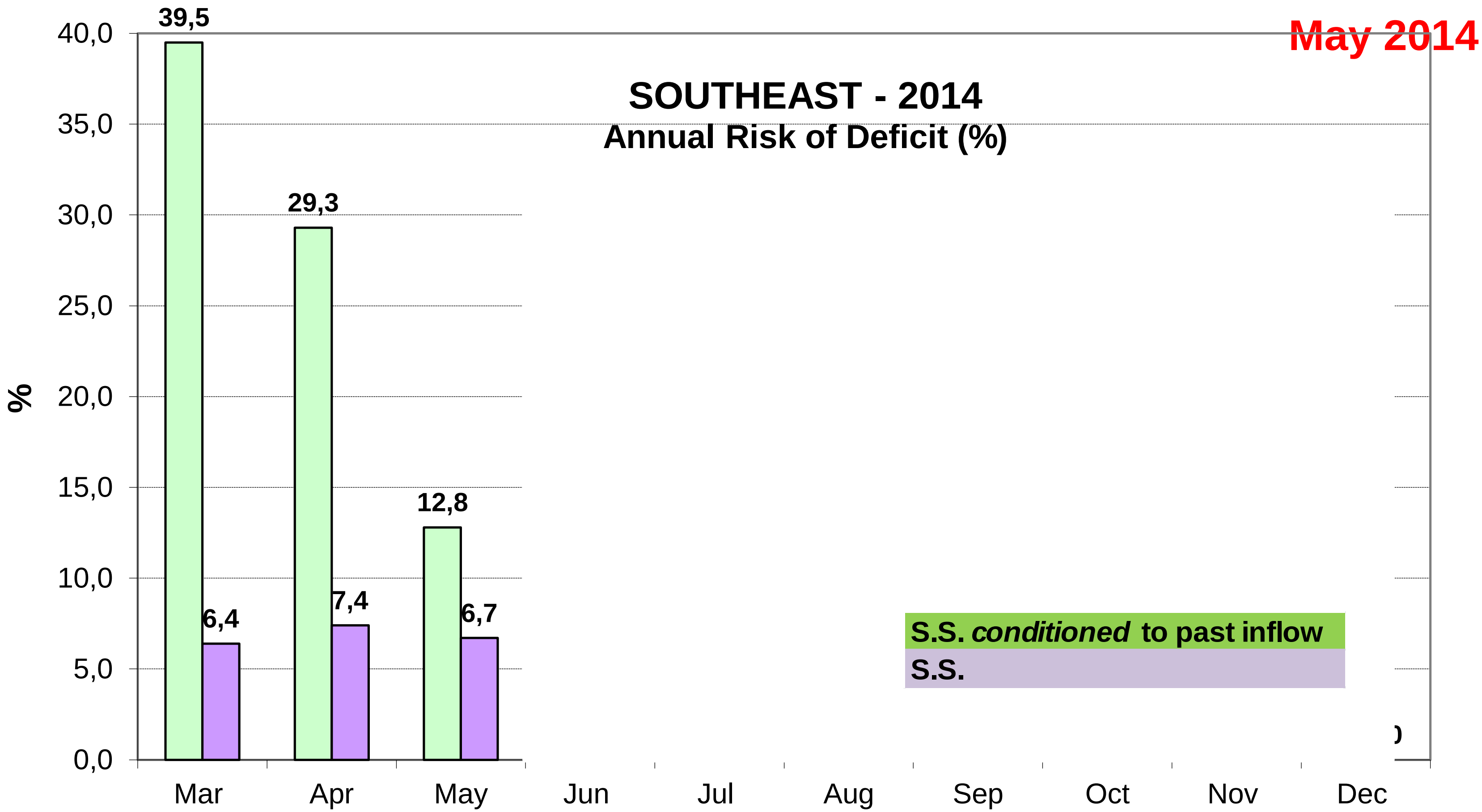
Indices calculated by PMOs - 2014



	Feb/14	mar/14
E inflow	39,00%	64%
Storage	35,40%	36,90%

Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

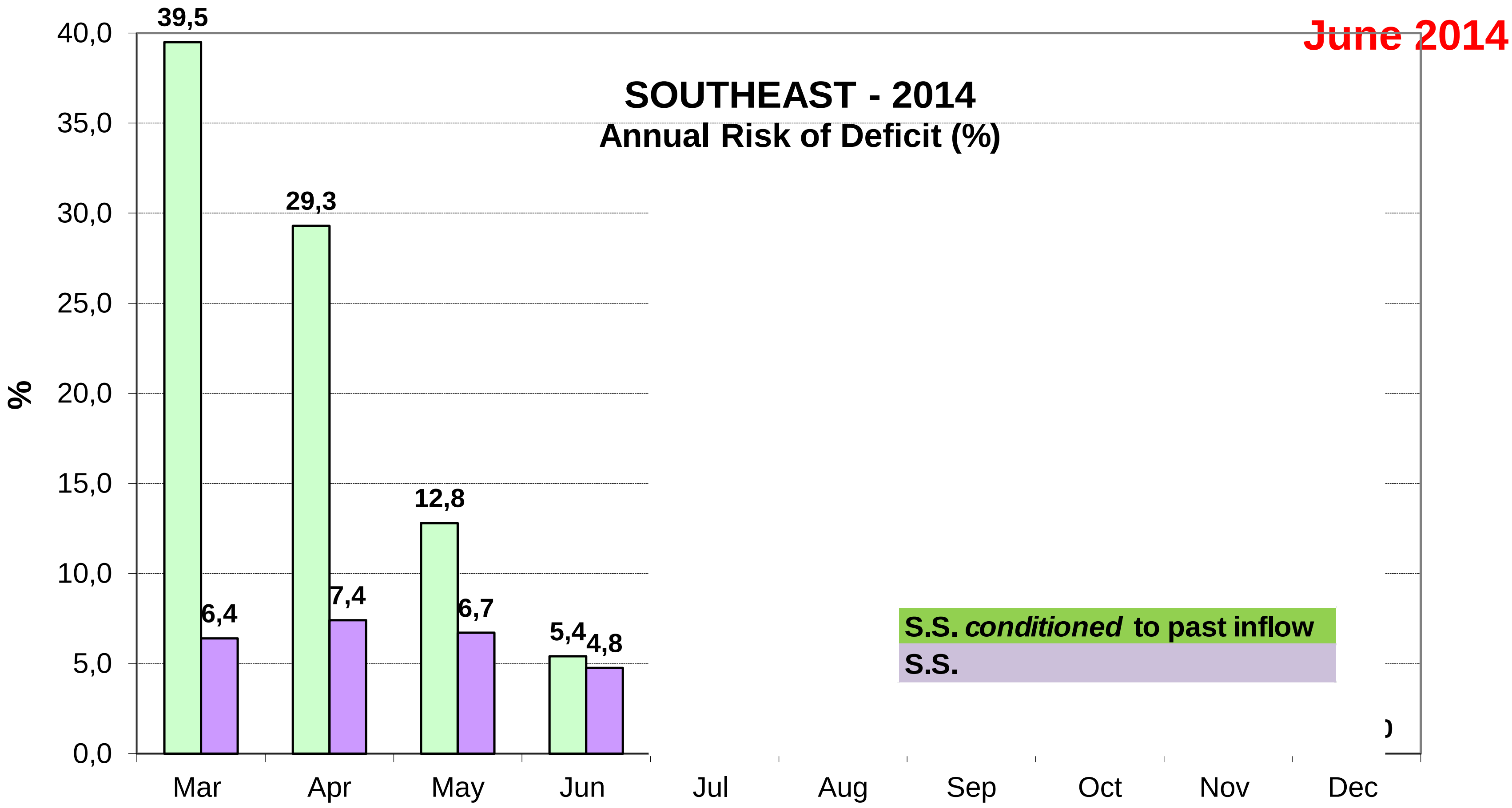
Indices calculated by PMOs - 2014



	Feb/14	mar/14	Apr/14
E inflow	39,00%	64%	80%
Storage	35,40%	36,90%	38,5%

Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

Indices calculated by PMOs of 2014

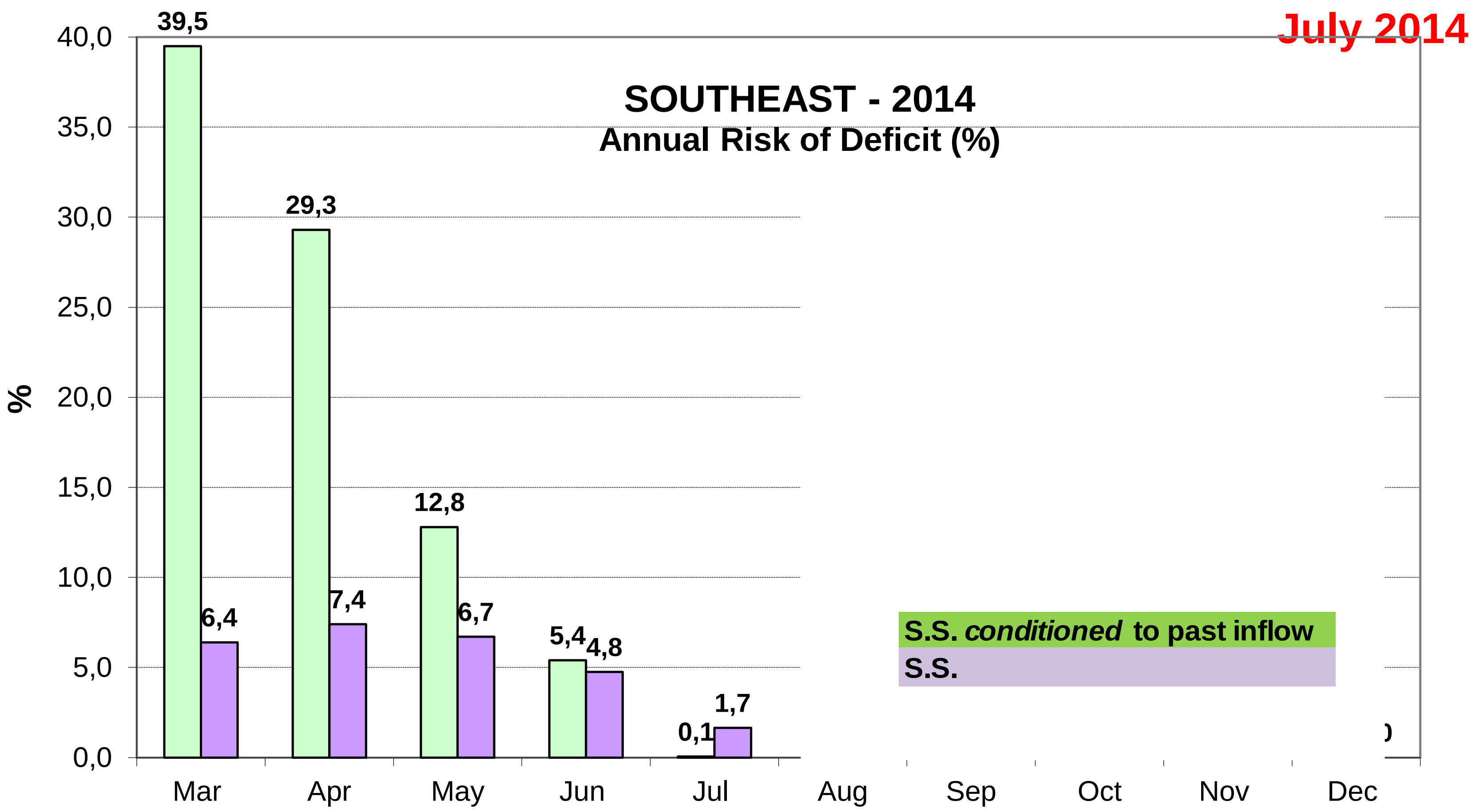


	Feb/14	mar/14	Apr/14	May/14
E inflow	39,00%	64%	80%	76%
Storage	35,40%	36,90%	38,5%	37,4%

Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

Eletrobras Cepel

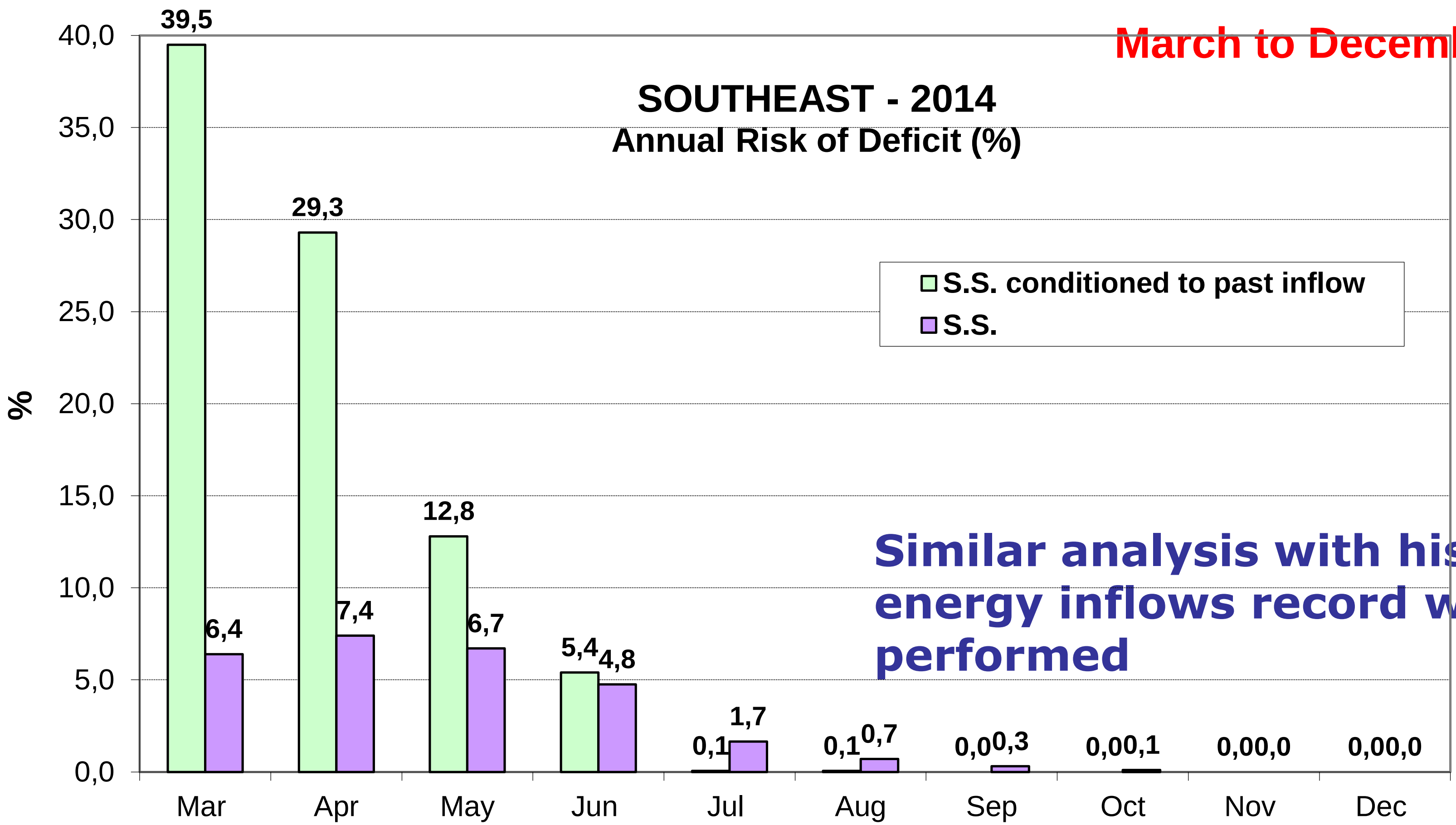
Indices calculated by PMOs of 2014



Probability of Annual Energy Deficit in 2014 at each Time of Evaluation

Eletrobras Cepel

Indices calculated by PMOs of 2014



March to December 2014

Similar analysis with historical energy inflows record were performed

Analysis with DECOMP model were performed considering similar historical scenarios

Energy Deficit Risks Comparison between Years 2001 and 2014/2015

Energy Inflows (ena) and Initial Reservoir Storages (earm)

2014 and 2001

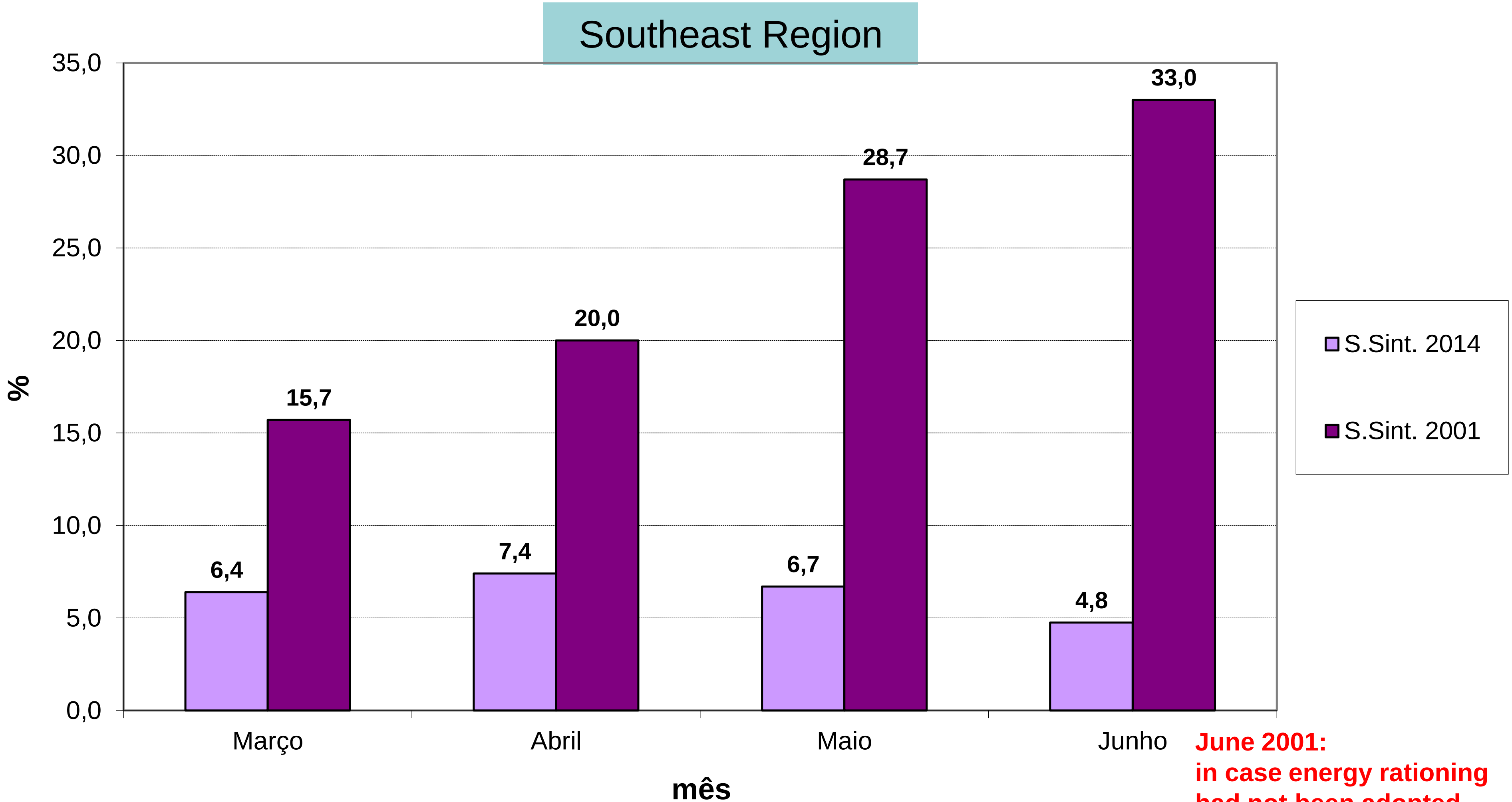
Em Fev 14	SE	S	NE	N
ena	39,0%	59,0%	27,0%	100,0%
earm	35,4%	37,6%	42,2%	80,0%

Em Fev 2001	SE	S	NE	N
ena	72,7%	241,4%	36,9%	82,2%
earm	35,1%	98,3%	38,4%	85,1%

Em Mar 2014	SE	S	NE	N
ena	64,0%	166,0%	26,0%	116,0%
earm	36,9%	46,2%	41,7%	83,8%

EmMar 2001	SE	S	NE	N
ena	70,8%	178,9%	31,7%	78,7%
earm	34,9%	96,2%	37,6%	85,8%

Monthly Operational Planning Results for March to June – 2014 and 2001



June 2001: in case energy rationing had not been adopted

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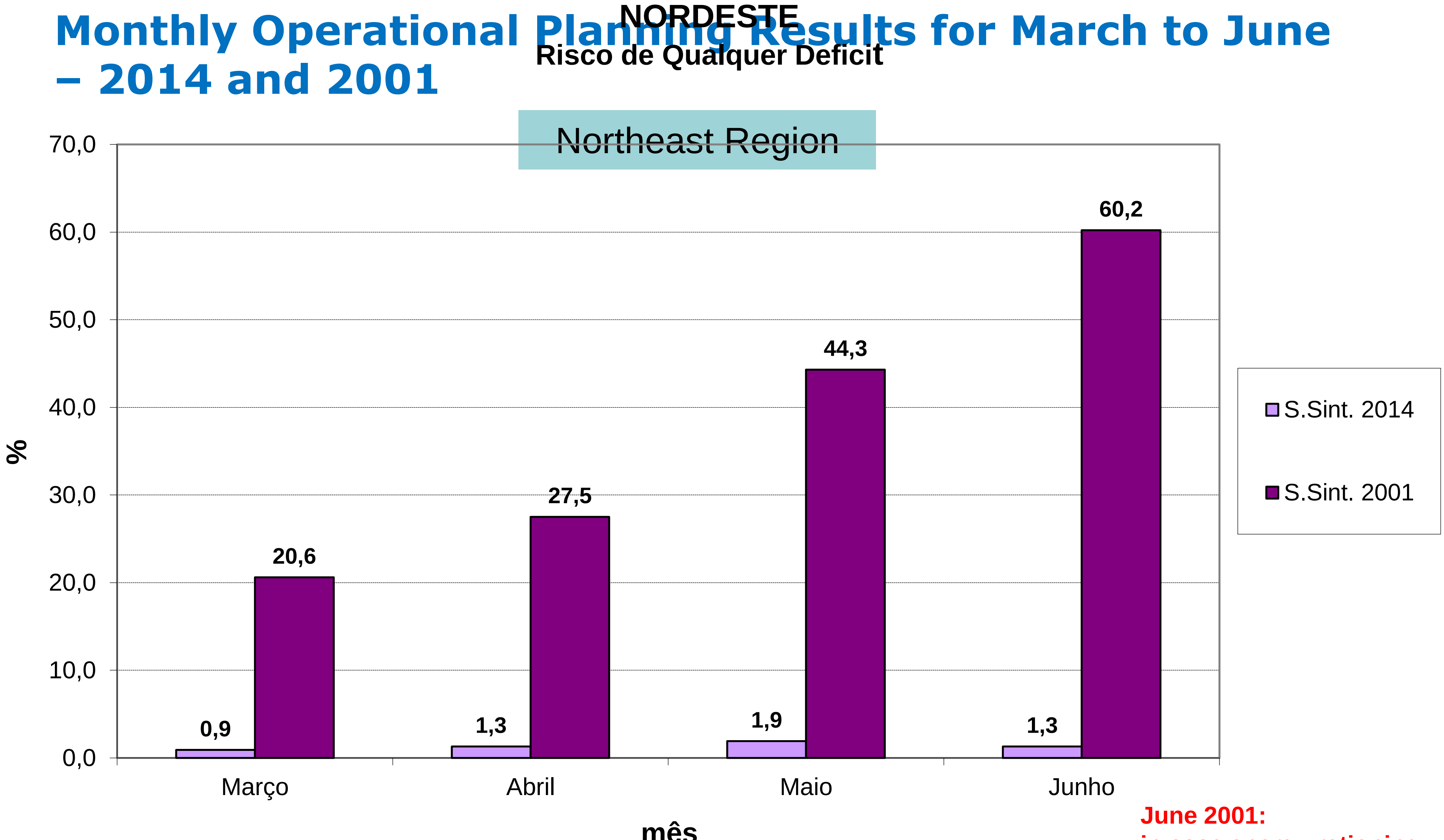
Monthly Operational Planning Results for March to June – 2014 and 2001



June 2001:
in case energy rationing
had not been adopted

Conclusion Remarks

One key parameter to support the decision of implementing or not an energy rationing in Brazil, in 2014 and 2015, was the stochastic optimization studies based on Cepel's chain of optimization models

Therefore, the decision of not implementing energy rationing was taken based on technical evaluation

Thank you !

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