Laboratory of Applied Mathematical Programming and Statistics
Electrical Engineering Department of PUC-Rio

STATISTICAL MODELING FOR RENEWABLE ENERGY

PROF. ÁLVARO VEIGA
alvf@ele.puc-rio.br

OSIRIS/EDF

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Agenda

- LAMPS: Laboratory of Applied Mathematical Programming and Statistics
- Brazilian Power System Overview
- Regulatory issues:
  - Centralized Operation
  - Spot price → PLD (Differences liquidation price)
- Energy market and risk
  - ACR (Regulated negotiation environment)
  - ACL (Deregulated negotiation envrironment)
- Conjoint scenario generation method for price and renewable energy
  - Large dimension VARX via LASSO
  - Scenario generation
- Historical wind data extension
  - From satellite data and physical models
  - From nearby sites

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Applied Mathematical Programming
and Statistics

Laboratory of Applied Mathematical Programming and Statistics

- LAMPS:
  - 5 Researchers
  - 10 to 15 student
- Areas of interest:
  - Energy
  - Quant. Methods in finance and insurance
- Research
  - Mathematical Programming
    - Stochastic programming with risk restriction
    - Robust Optimization
  - Statistical modeling
    - Non linear / non Gaussian modeling
    - Model and variable selection
    - Large dimension
    - Scenario generation
  - Quantitative methods in Finance
    - Pricing methods
    - ALM (Asset Liability Management)

Contracts with the industry

- Optimization of portfolio for contracts of renewable energy
  - MPX, since 2013
- Computational tool for optimal hydro and wind power
  - UTE - Norte Fluminense **(EDF)**, 2011-2013
- Optimal debt issuing for oil companies
  - Petrobras, 2010-2012
- IBNR evaluation for the DPVAT (Compulsory Limited Motor Third-Party Liability)
  - Seguradora Lider, since 2013
- Persistency analysis for life products
  - LIMRA/Bradesco, 2012
- Generation quality indicators for power plants.
  - IPEA, 2011-2013
- Internal models for life products
  - Mongeral, 2010-2011.
- ALM for public retirement program in Angola
  - Angola Government/DGM, 2008-2009

System Overview

Brazilian System Overview: big numbers

- Area: 8.5 millions of Km^2 (US cont. + ½ Alaska)
- Population: 190 million
- Expected GDP growth: 4.7%
  - → 2003-2008: 4.2%, 2009: -0.3%
  - → 2010: 7.5%, 2011-2012: 1.85%
  - → 2013: 2,3%
  - → 2014: expected: 1%
  - → **In 15 years we need to double today's installed capacity**

- Installed Capacity (2013): 127 GW
  - → 10% of the US capacity or 10% of the EU capacity
  - → 100xUruguai, 10xChile and 5xArgentina
- Energy Production (2012): 58.5 avgGW
  - → Nov/2012: 74% Hydro, 25% Thermal, 1% Wind
  - → Peak demand: ~ 72 GW.

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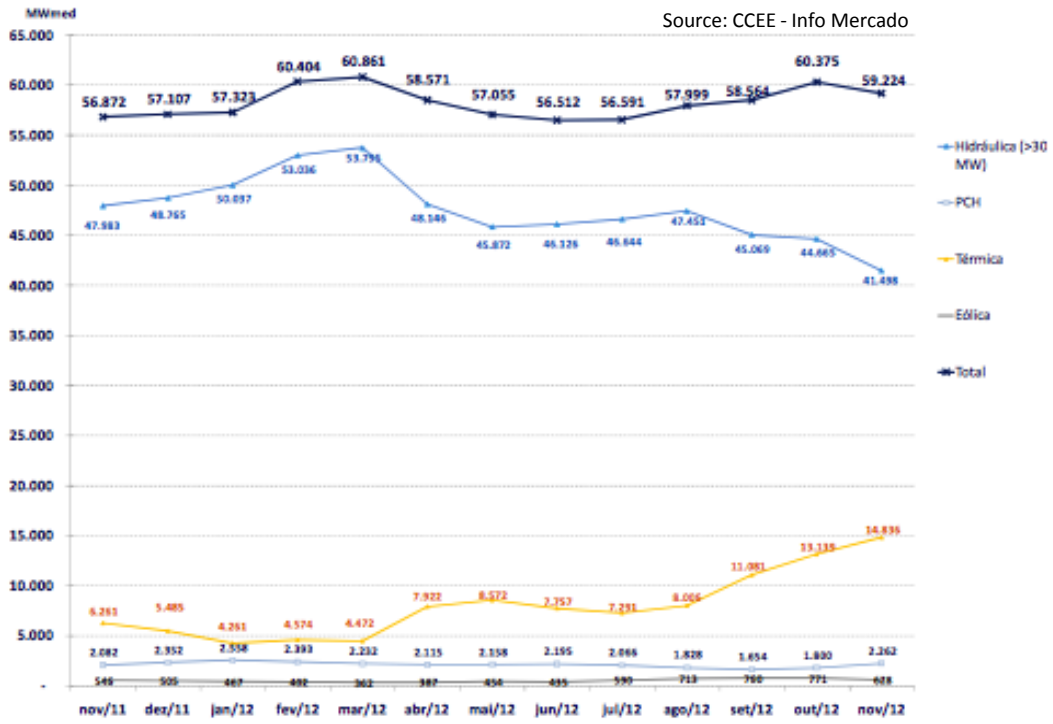
Brazilian System Overview: generation sources

Source: CCEE - Info Mercado



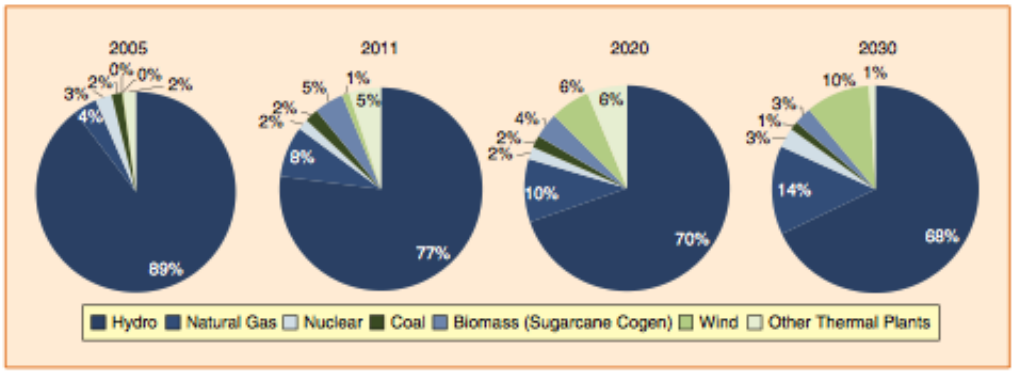


figure 5. Possible evolution of the Brazilian electricity matrix (source: PSR).

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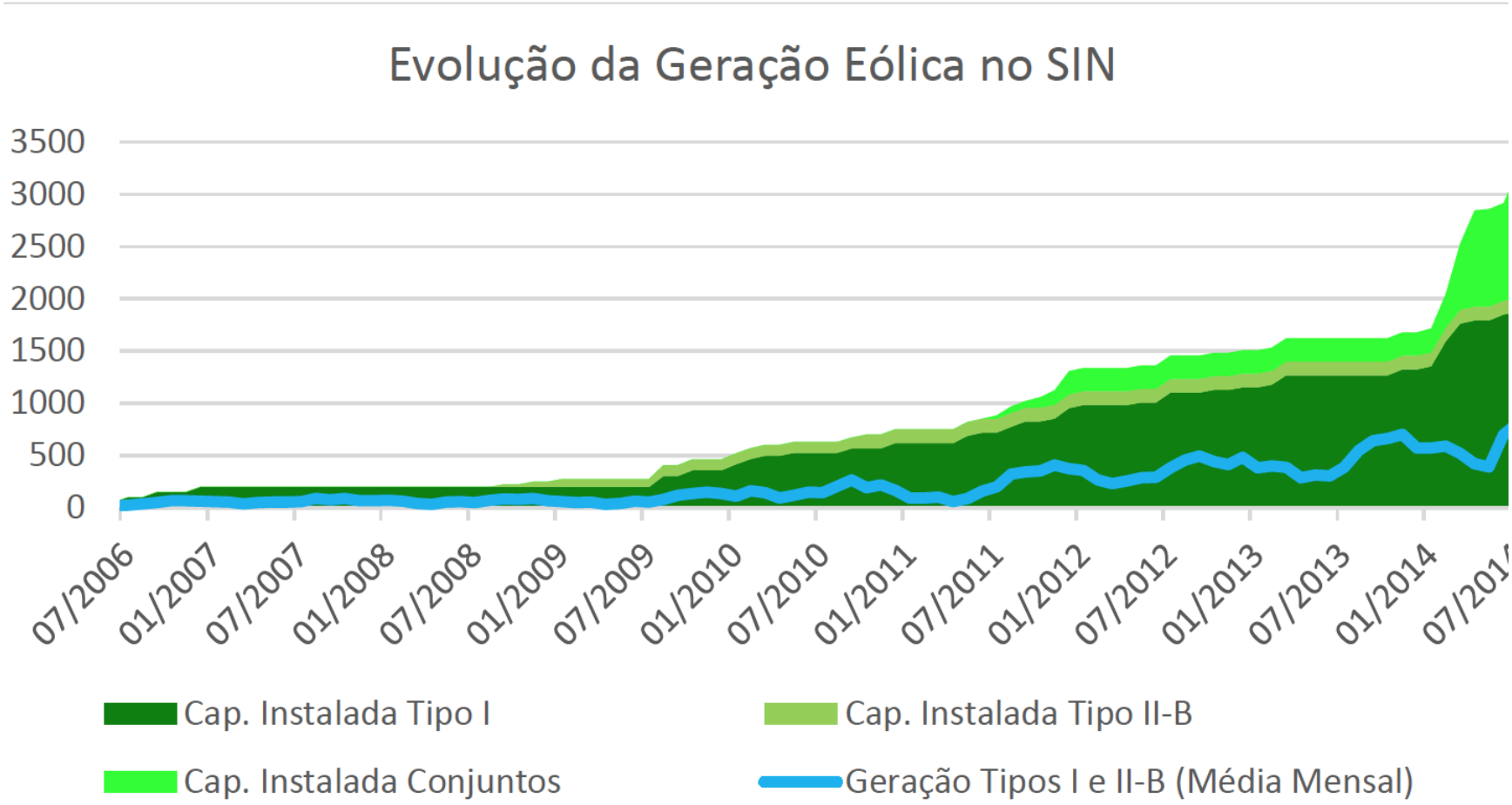
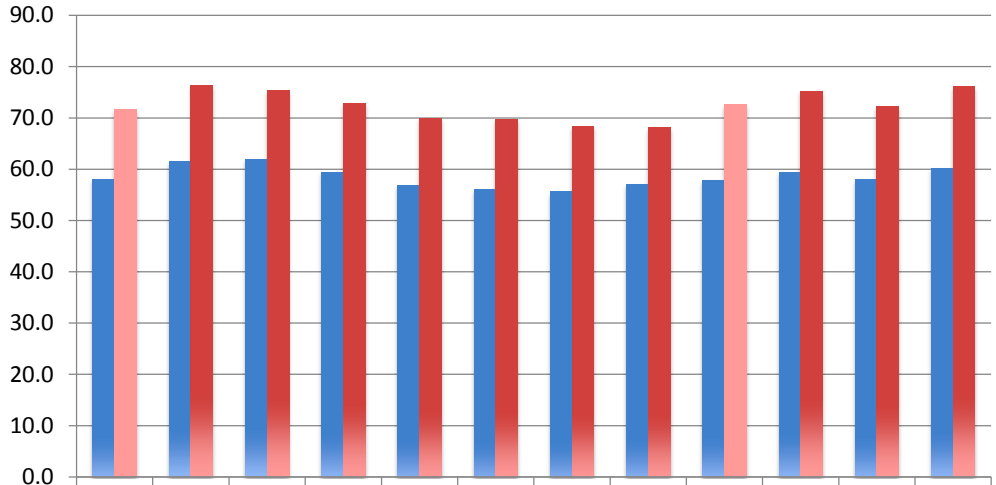
Wind power evolution in Brazil



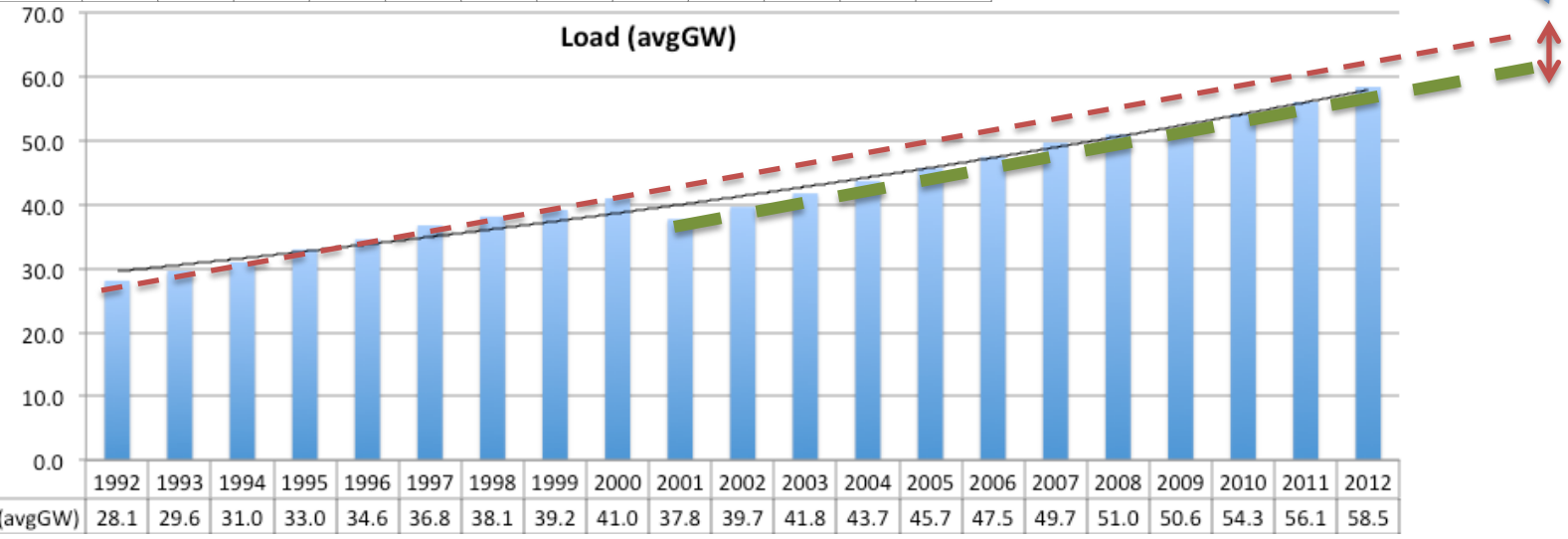
1 - Evolução da capacidade instalada de usinas eólicas e geração eólica verificada no SIN.
le usinas tipo II-B, a geração programada é contabilizada na geração total.

Brazilian System Overview: load growth



	Jan	Fev	Mar	Abr	Mai	Jun	Jul	Ago	Set	Out	Nov	Dez
Load 2012 (avgGW)	58.0	61.4	61.9	59.3	56.8	56.0	55.6	57.0	57.8	59.4	58.0	60.2
Peak load 2012 (avgGW)	71.7	76.3	75.3	72.9	69.9	69.8	68.3	68.1	72.5	75.1	72.1	76.0

Long term
Rationing effect



	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Load (avgGW)	28.1	29.6	31.0	33.0	34.6	36.8	38.1	39.2	41.0	37.8	39.7	41.8	43.7	45.7	47.5	49.7	51.0	50.6	54.3	56.1	58.5

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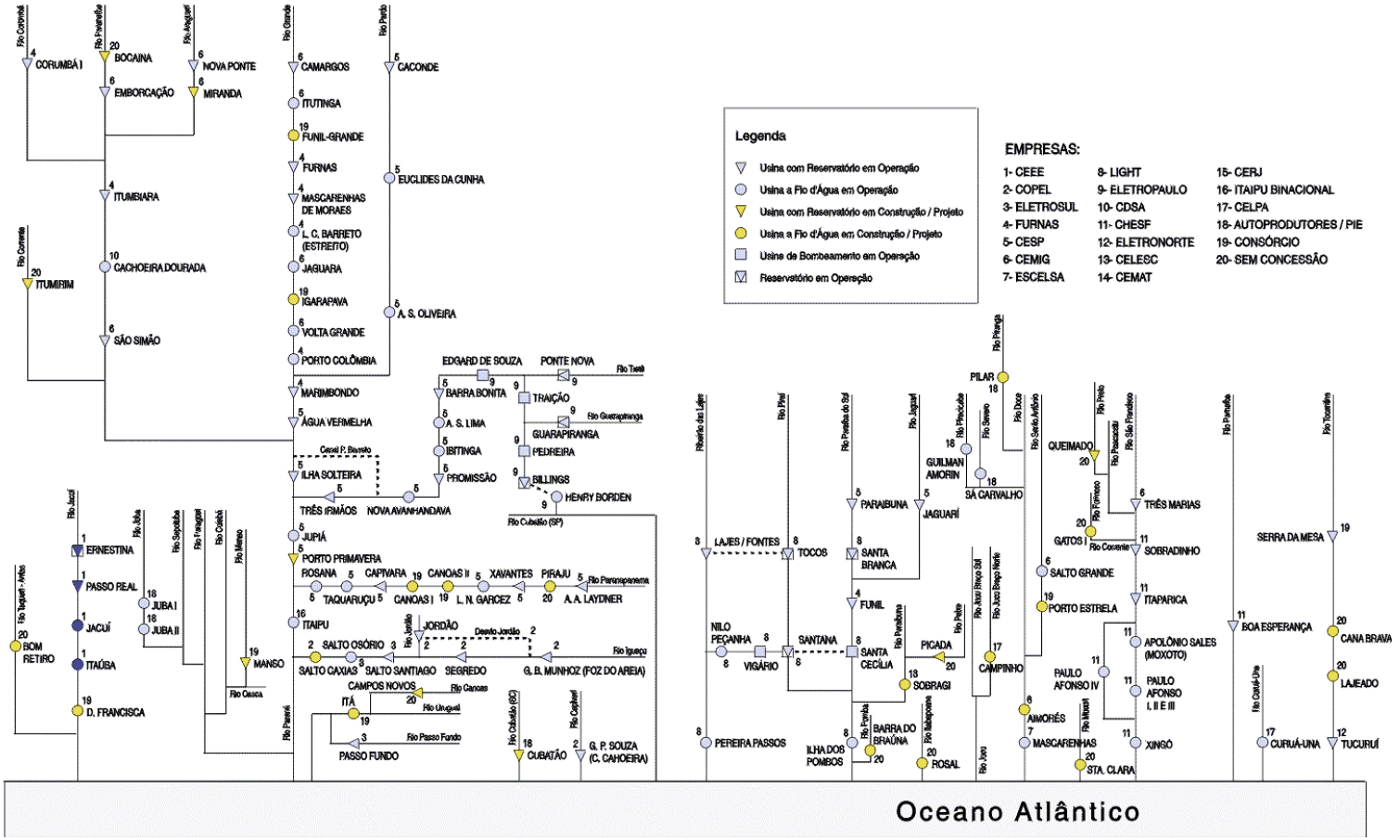
Brazilian System Overview: hydro topology

- More than 10 river basins
  - → Wide variety of weather patterns
  - → Different ownerships in the same rivers



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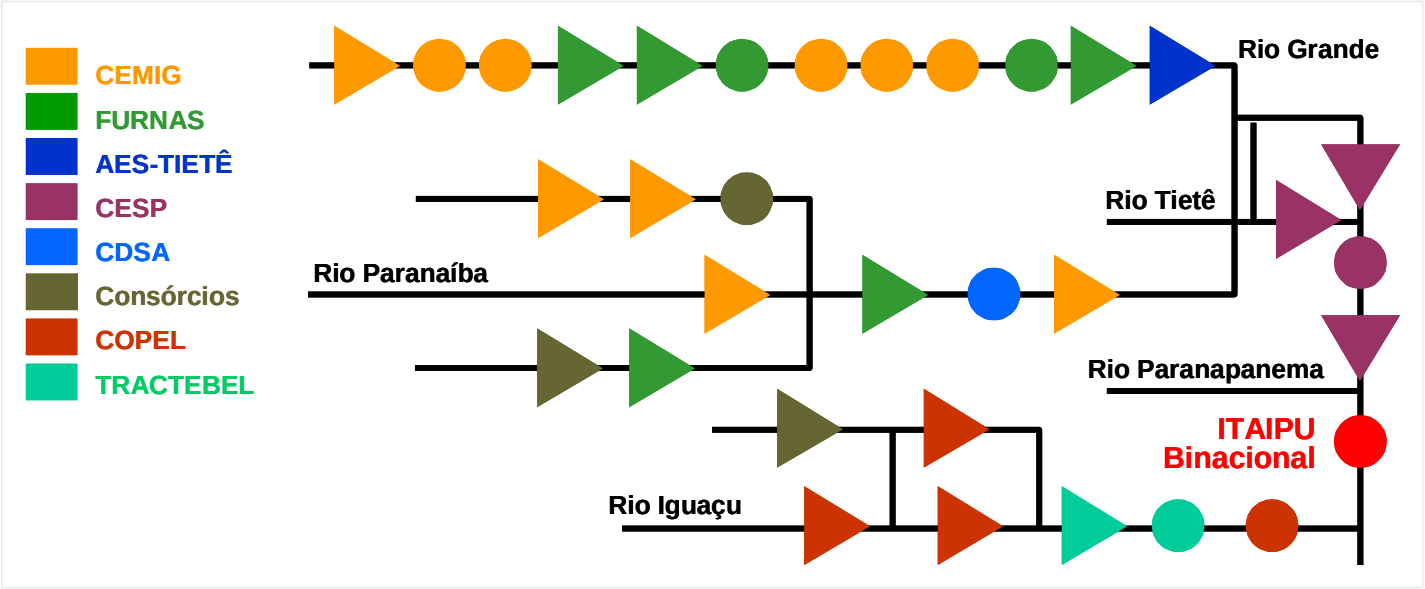
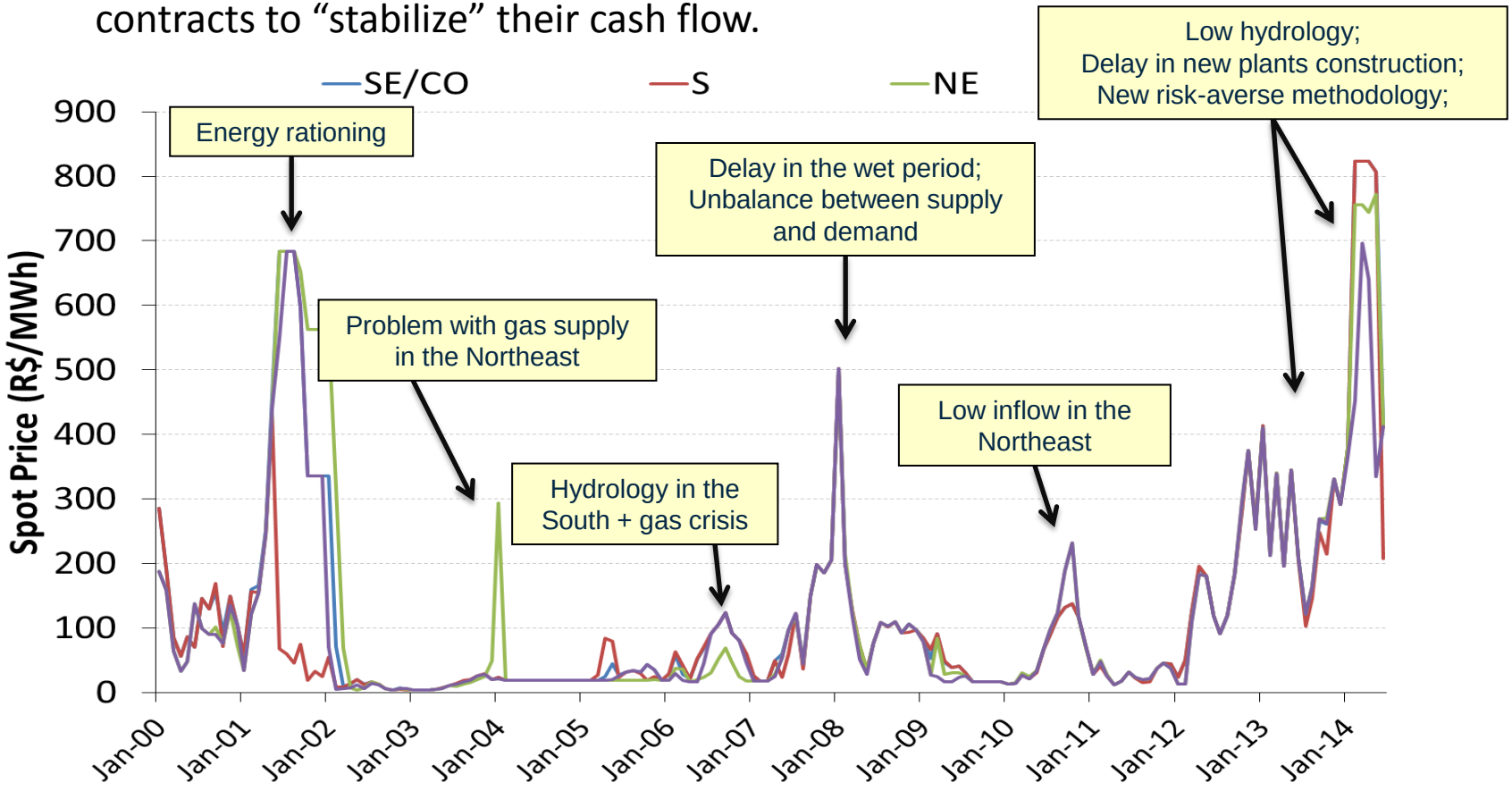


Centralized Dispatch and spot prices

- **Centralized dispatching: hydro-thermal model.**
- Long term: monthly, 10 years.
  - SDDP: Stoch. Dual Dynamic Prog. (Pereira and Pinto, 1985): NEWAVE
  - Takes into account the future demand and evolution of the system.
  - Simplified system → 4 'equivalent' reservoirs → stored energy (EARM)
  - ENA (natural inflow energy) = total energy if all inflow pass throught turbines
  - 'Historical' ENA's depends on the configuration of the system
    - Periodical Autoregressive Model: Par(p)
    - ENA's >0 but model is on the original scale → Scenario generation is problem
  - Outputs: 2000 trajectories for
    - Thermal Power, EARM, **Energy Price**= Marginal Operative cost= Cost of water,
    - For **ENAs** produced by the Par(p) model adapted to each configuration of the system.
- Medium term: weeks, 1 year
  - Deterministic, based on the long term planning
  - Weekly prices for liquidation of differences, PLD or SPOT PRICES.
  - 12 prices: 4 sub-systems, 3 time intervals during the day.
- Spot Price is a highly volatile and affected by external factors.
  - Market (hydrology, demand, supply, outages, fuel availability, delay in plant construction);
  - Political (interference on prices, out of merit dispatches, change in the operation methodology).

Historical Spot Price

- External factors may create “unexpected” spot price spikes.
  - Long periods with low spot prices and short periods with very high prices;
  - To hedge against this volatility, generators and consumers sign long-term contracts to “stabilize” their cash flow.



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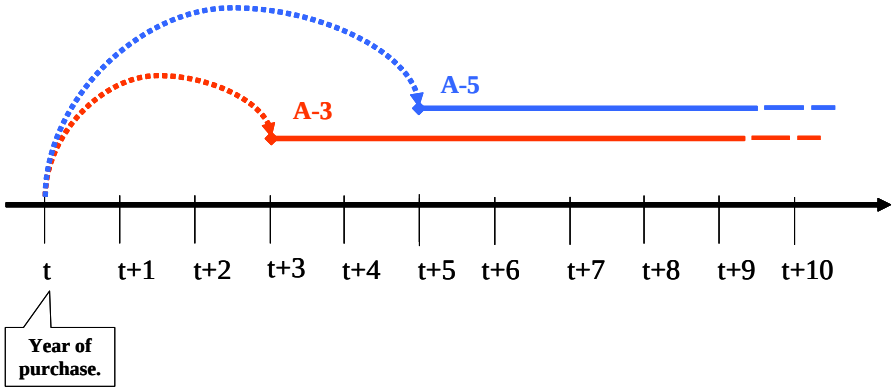
Energy Market and Risk

Energy Market – Two negotiation environments

- **Regulated Environment (ACR): ¾ of total energy**
  - Auctions for new capacity: 3 and 5 years ahead
  - Long-term contracts between DISCOs and GENCOs
  - 30 years for hydros, 20 for wind, and 15 for thermal

→ **LOW RISK: differences are partially cleaned once a year by the spot price**

- Capacity contract
  - Generator's risk
- Availability contract
  - Distributor's risk



- **Free Environment (ACL): ¼ of total energy**
  - Free Consumers
    - more than 3 MW of load or 0.5MW if contracted with renewables
  - Trading companies and GENCOs freely negotiate prices, quantities and clauses
  - Contracts horizon range from 1 month to 5 years
  - Contracts are usually forward (quantity)

→ **HIGH RISK: differences are cleaned every week by the spot price**

Brazilian Energy Exchanging - BRIX

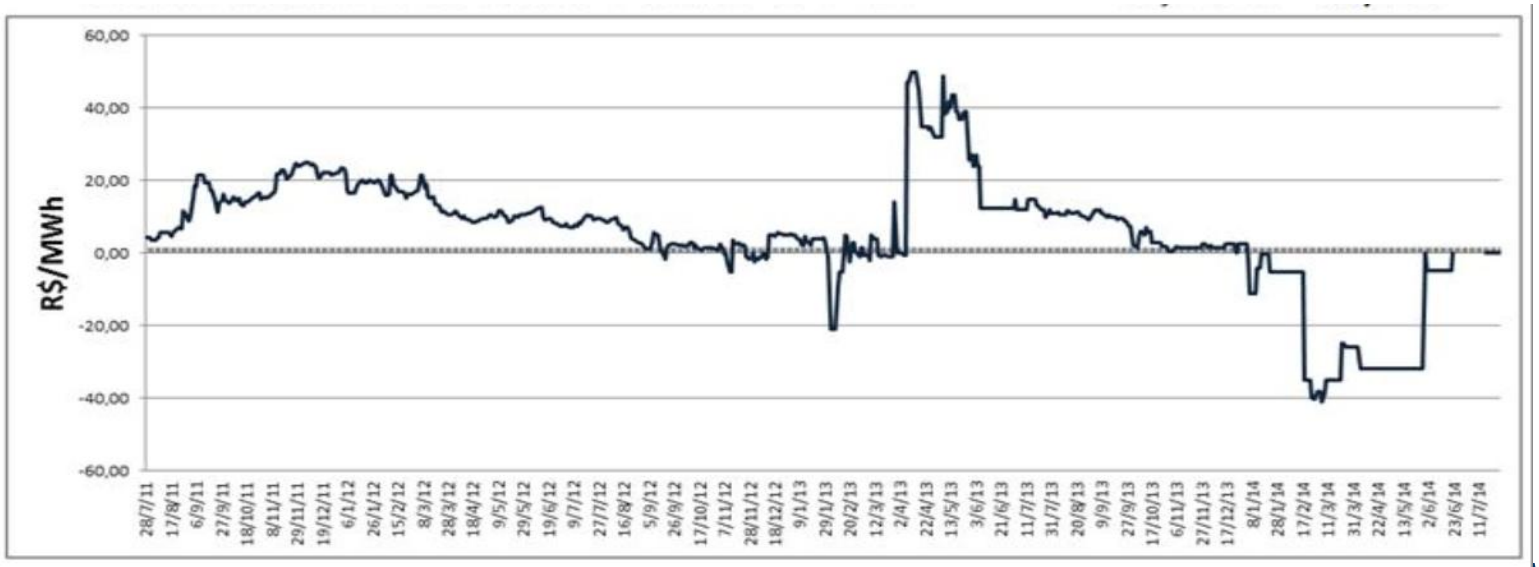
- BRIX – Brazilian Intercontinental Exchange (www.brix.com.b)
  - Created en 2010, 40GW / 11 MI eur (R$ 35 bi)
  - Players
    - CSP (Concentrated Solar Power) , PIE (Independent Power Producer)
    - APE (Alternative Power & Energy), Energy traders
    - Free Consumers (load .> 3000 kW)
    - Free Special Consumers (load > 500kW, buy renewable energy*)

    * renewable energy = small hydro, biomass, sanitary landfill
  - Contracts
    - Month, Quarter, Semester, Year, Swaps, Collar
    - Spot price or spread over PLD

Brix prices

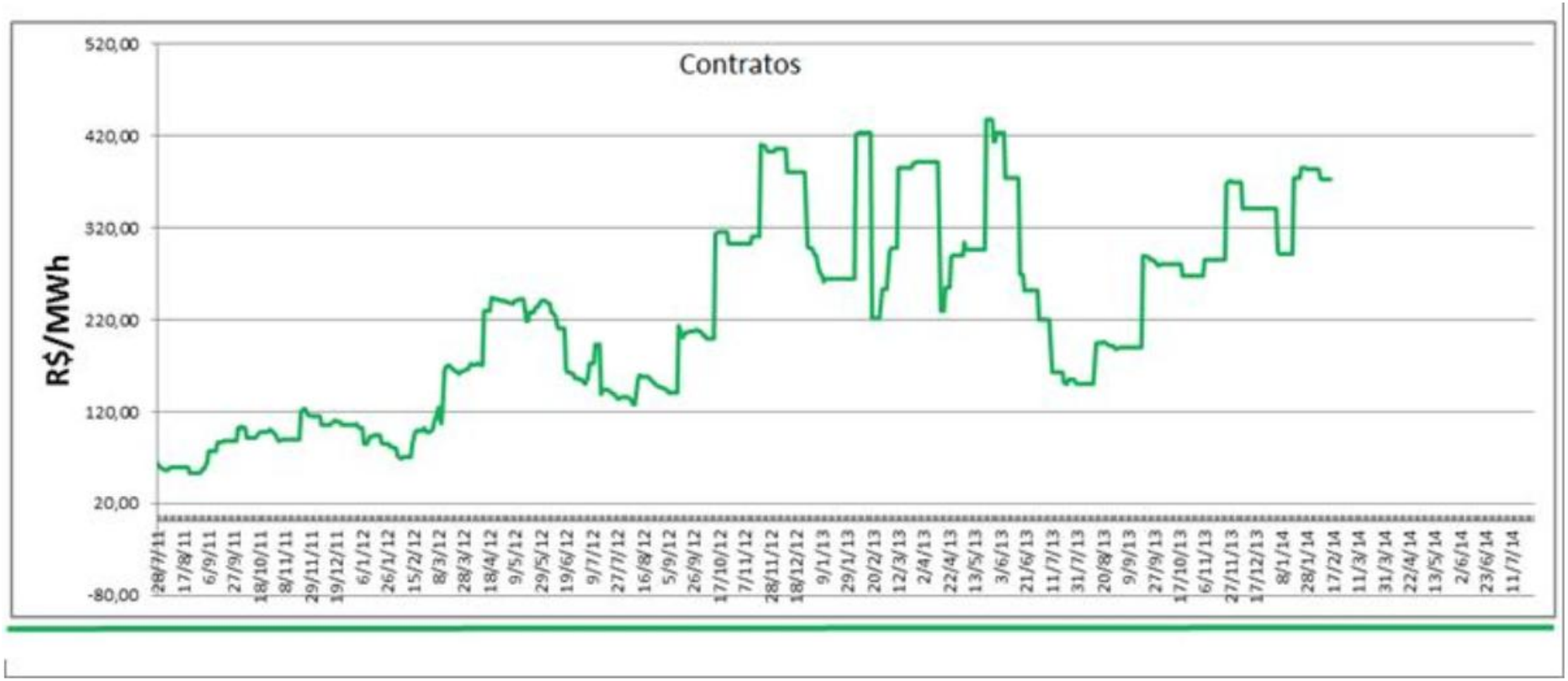
- Term Structure

- Spread over PLD 28/07/2011- 29/07/2014



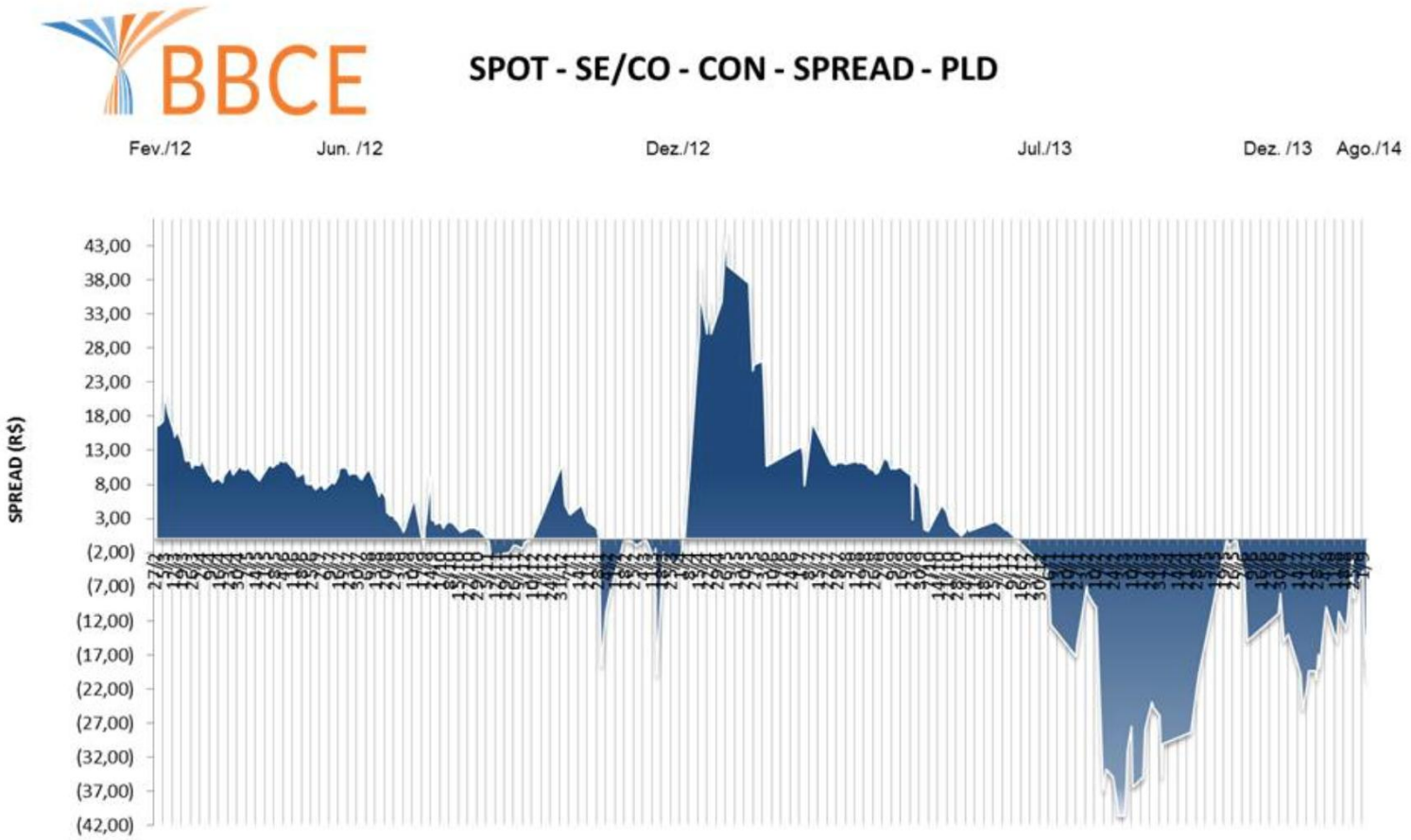
Brix prices

- Renewable energy (reduced transport fees) 28/07/2011- 29/07/2014



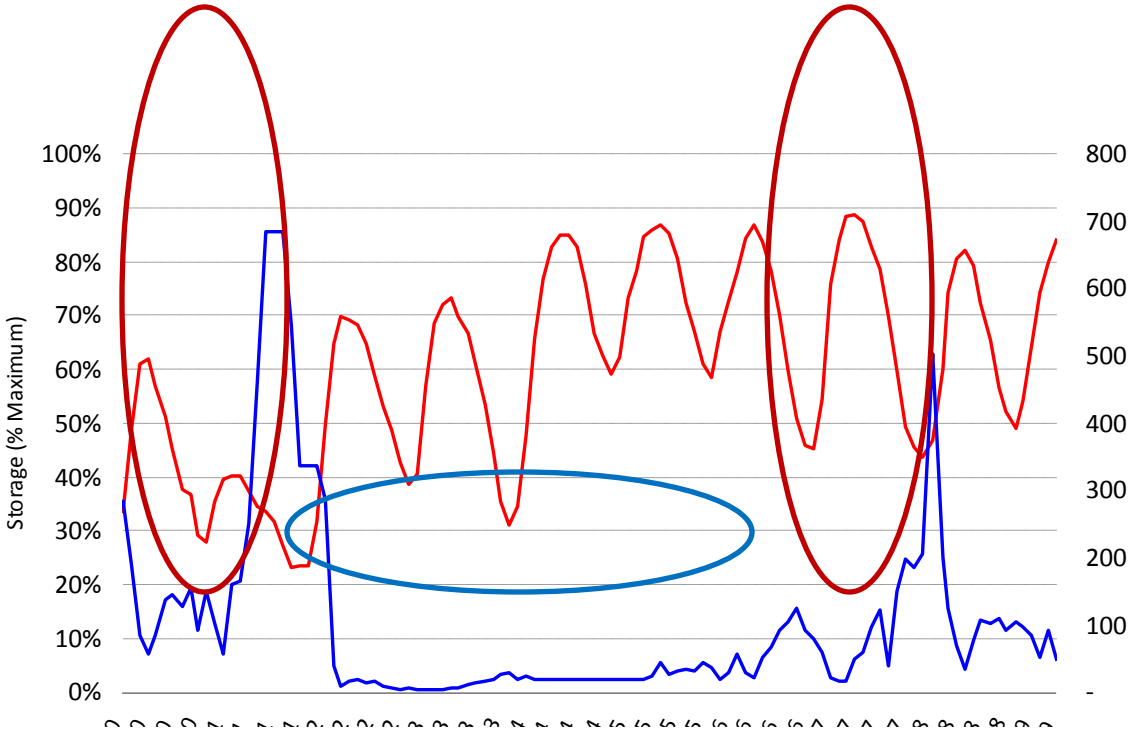
Balcão Brasileiro de Comercialização de Energia - BBCE

- BBCE: (www.bbce.com.b)
  - Created en 2013, 3.6GW / 30 mi eur (>R$ 90 mi)



Risk: Spot Prices and Stored Energy in reservoirs

- Short-term “Market” prices are very volatile and skewed
  - → Strongly (negatively) correlated with systems storage
    - → Hydro and Wind power plants suffer from the two-sided (price&quantity) risk :
      - → Short in contracts: Long periods selling by low short-term prices
      - → Long in contracts: Short periods purchasing by high short-term prices



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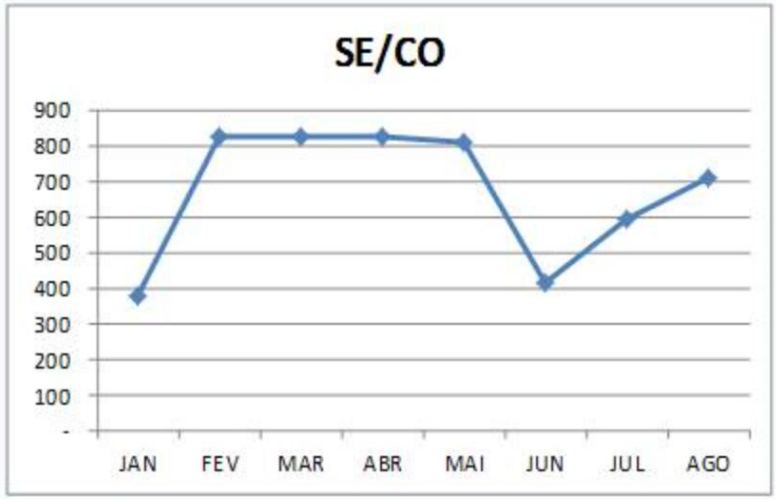
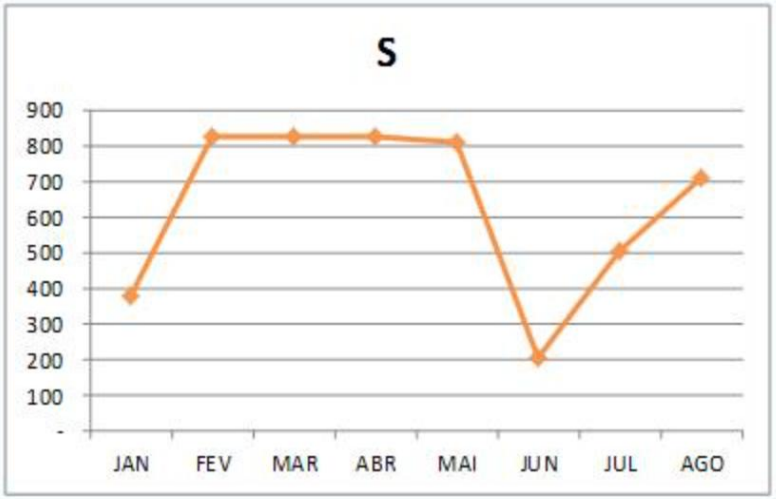
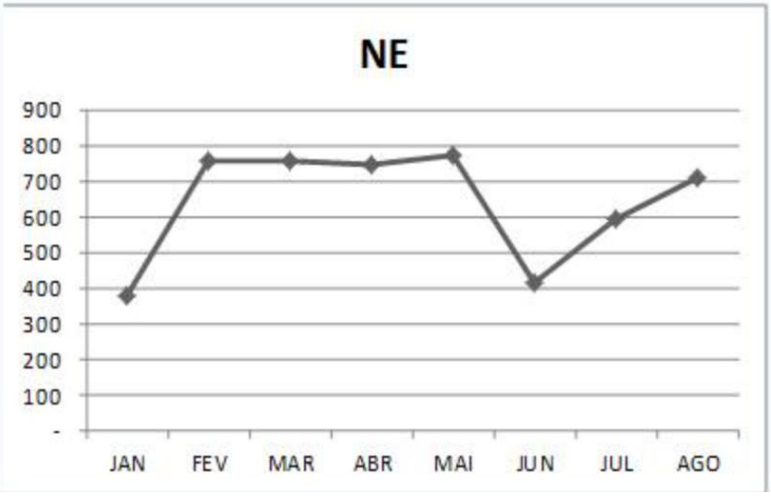
BBCE

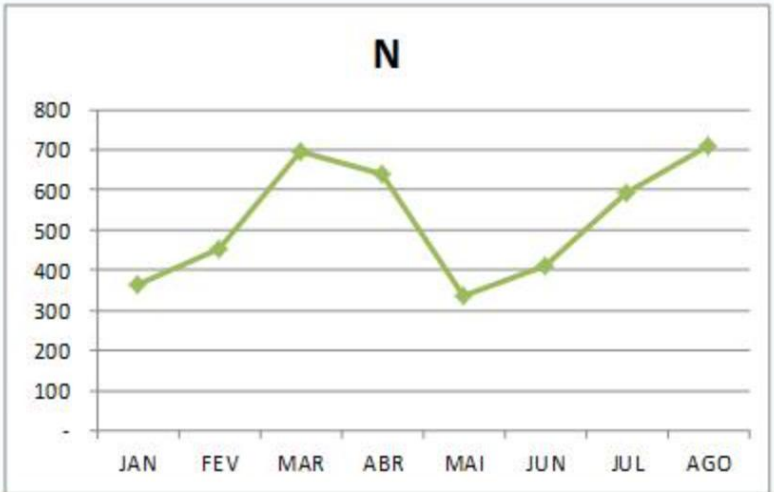
Média Mensal - PLD 2014 - Submercados

BBCE

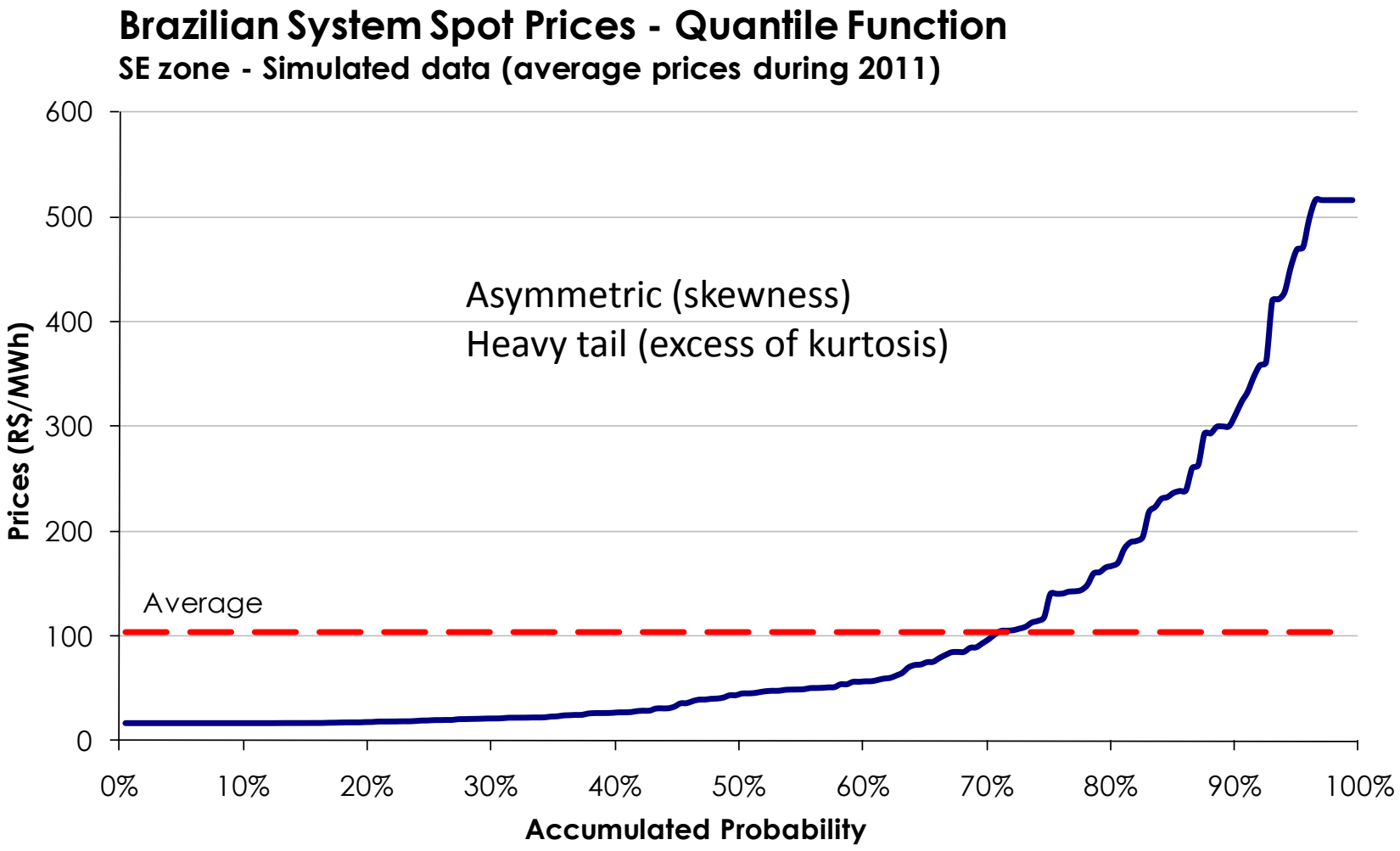








Brazilian System Overview: risk in the contract market



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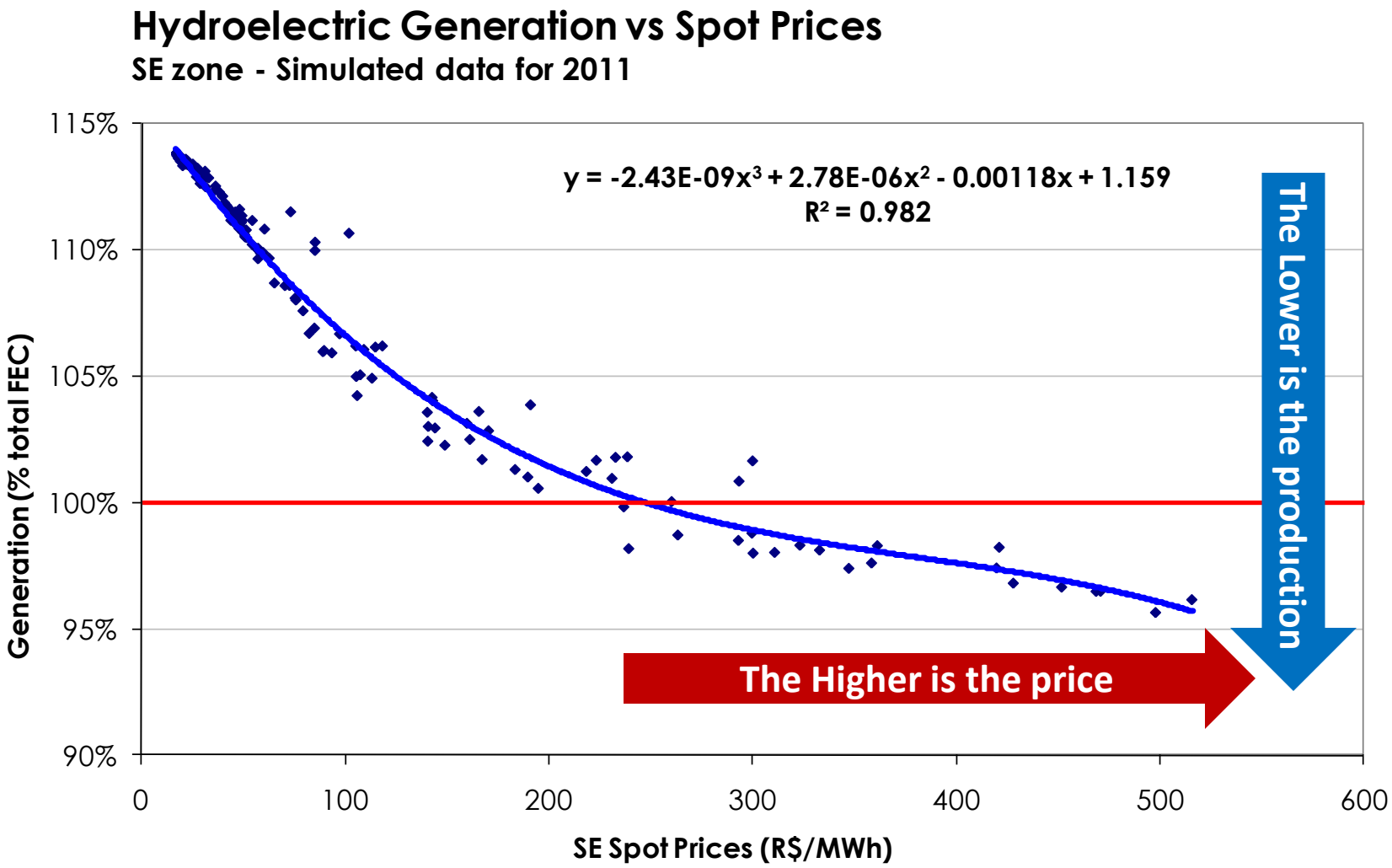

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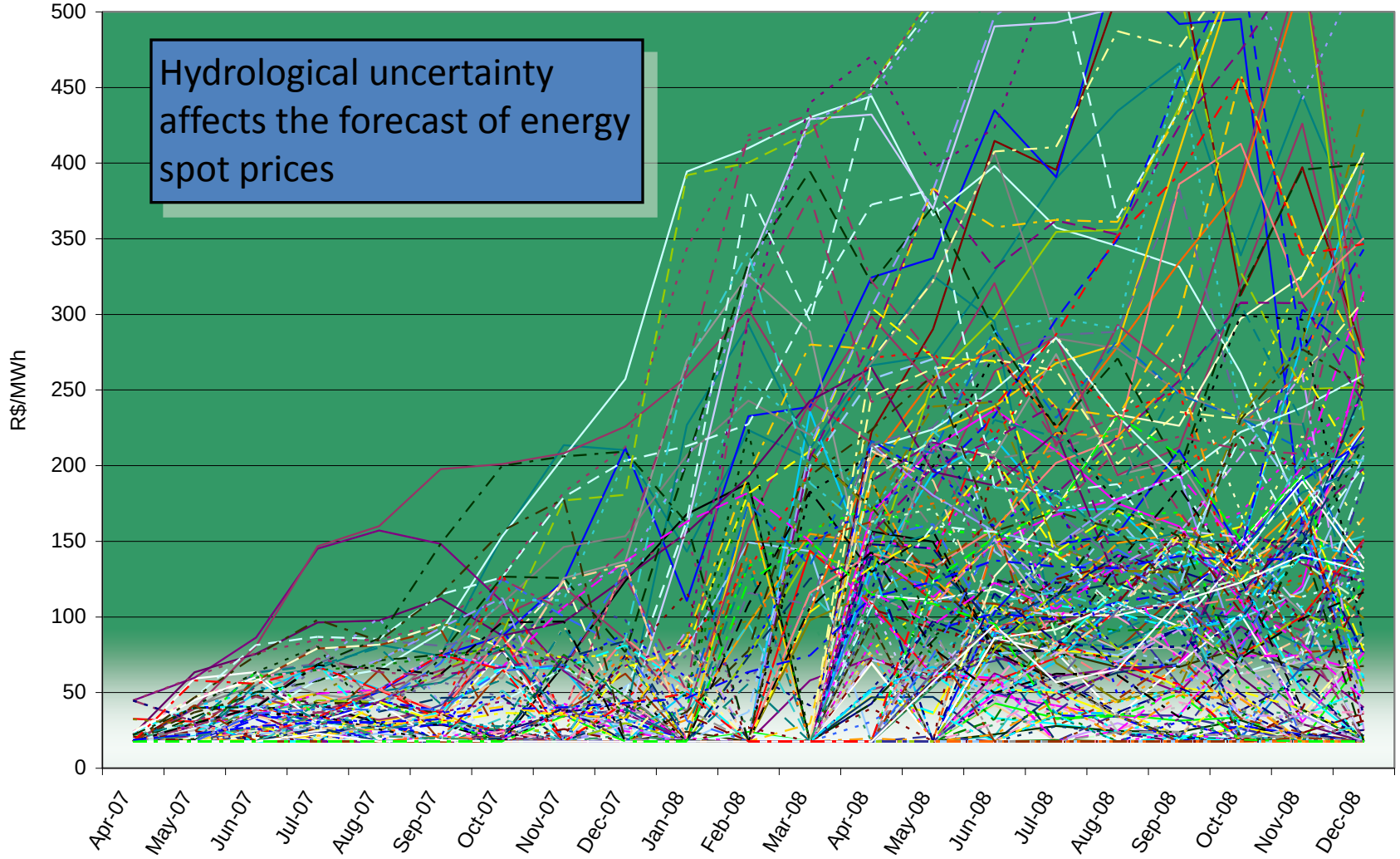

Figure Powered by PSR Consulting

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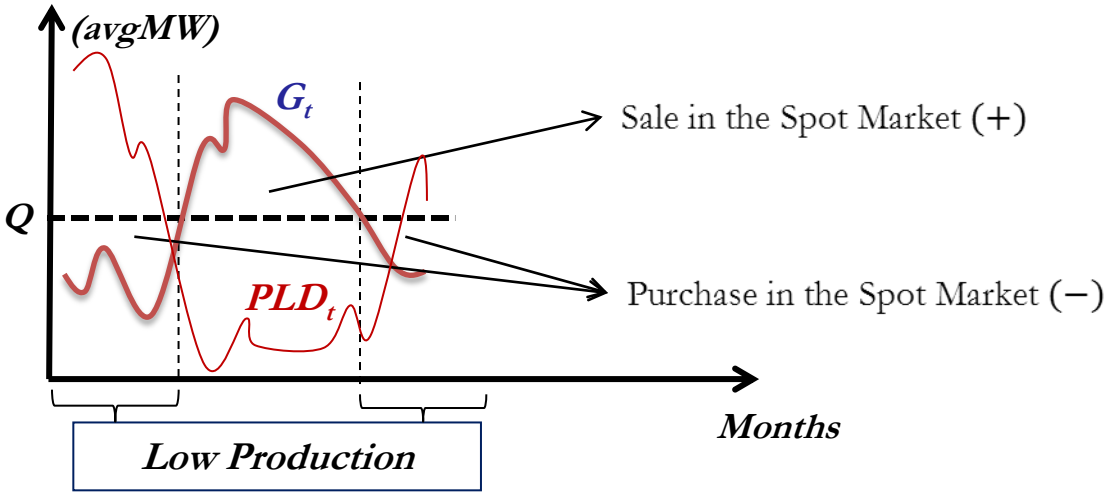
Renewables in the Free Enviroment: price x production risk

- Forward Contracts:

$$R(G_t; PLD_t) = P^V h_t Q + (G_t - Q) PLD_t h_t$$



Risk Assessment: Free Environment (ACL)

- **Simulate the contract revenue for 1 to 5 years (monthly based)**
  - **Small Hydro (run of river) and Wind Power are complementary**
  - **We need to capture the joint generation (hydro and wind) and spot dynamic in a single multivariate model**