Modelling Tools for Brazilian Energy Planning

ILAS 2019

EPE

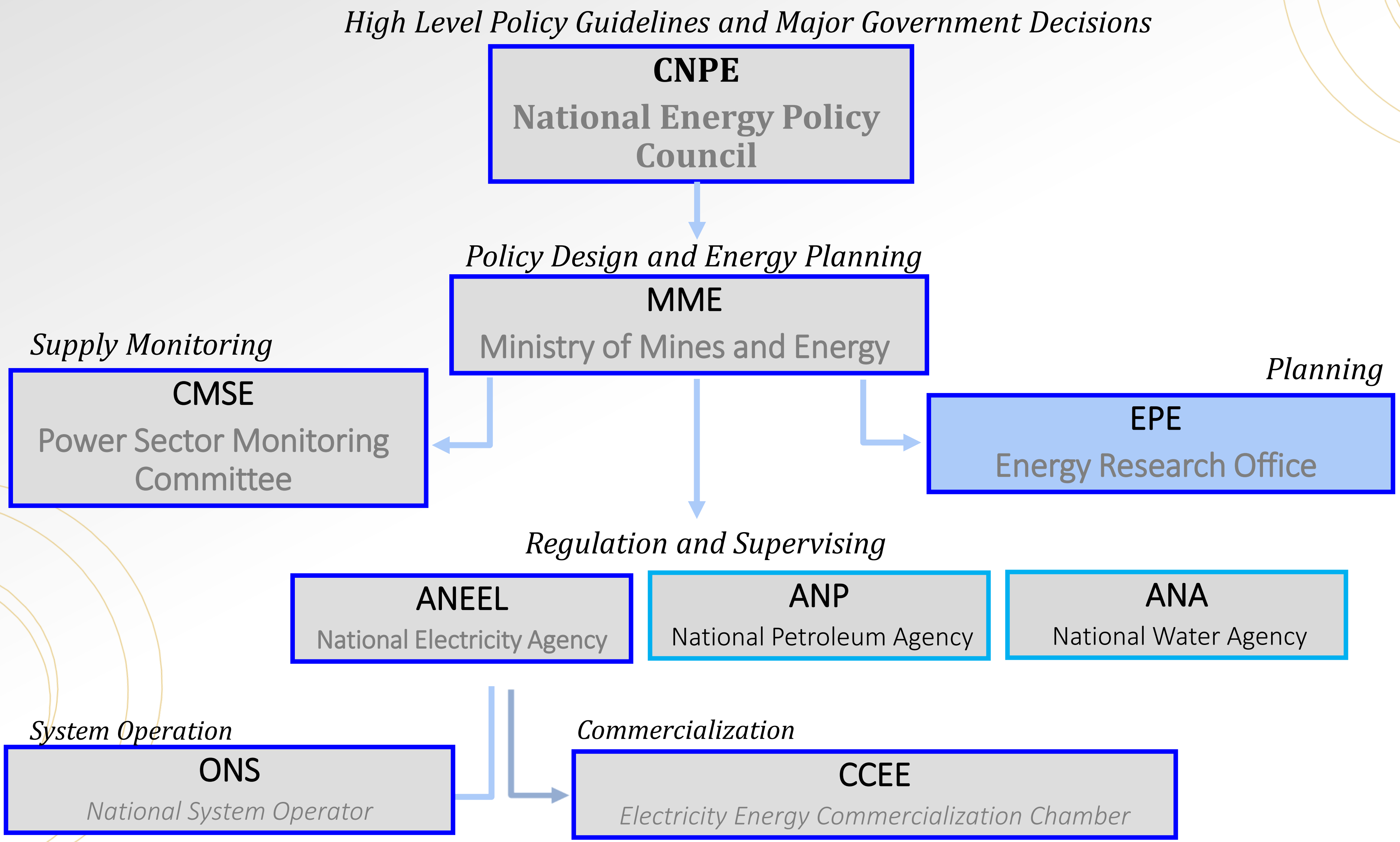
AGENDA

➢ BACKGROUND ON BRAZILIAN ENERGY SECTOR AND EPE

- ✓ INSTITUTIONAL STRUCTURE OF BRAZILIAN ENERGY INDUSTRY
- ✓ EPE
- ✓ ENERGY AND ELECTRICITY
- ✓ MODELLING TOOLS FOR ENERGY PLANNING
- ✓ TEN-YEAR GENERATION PLAN
- ✓ NATIONAL LONG TERM ENERGY PLAN
- ✓ REFERENCE SITES

Background on Brazilian Energy Industry and EPE

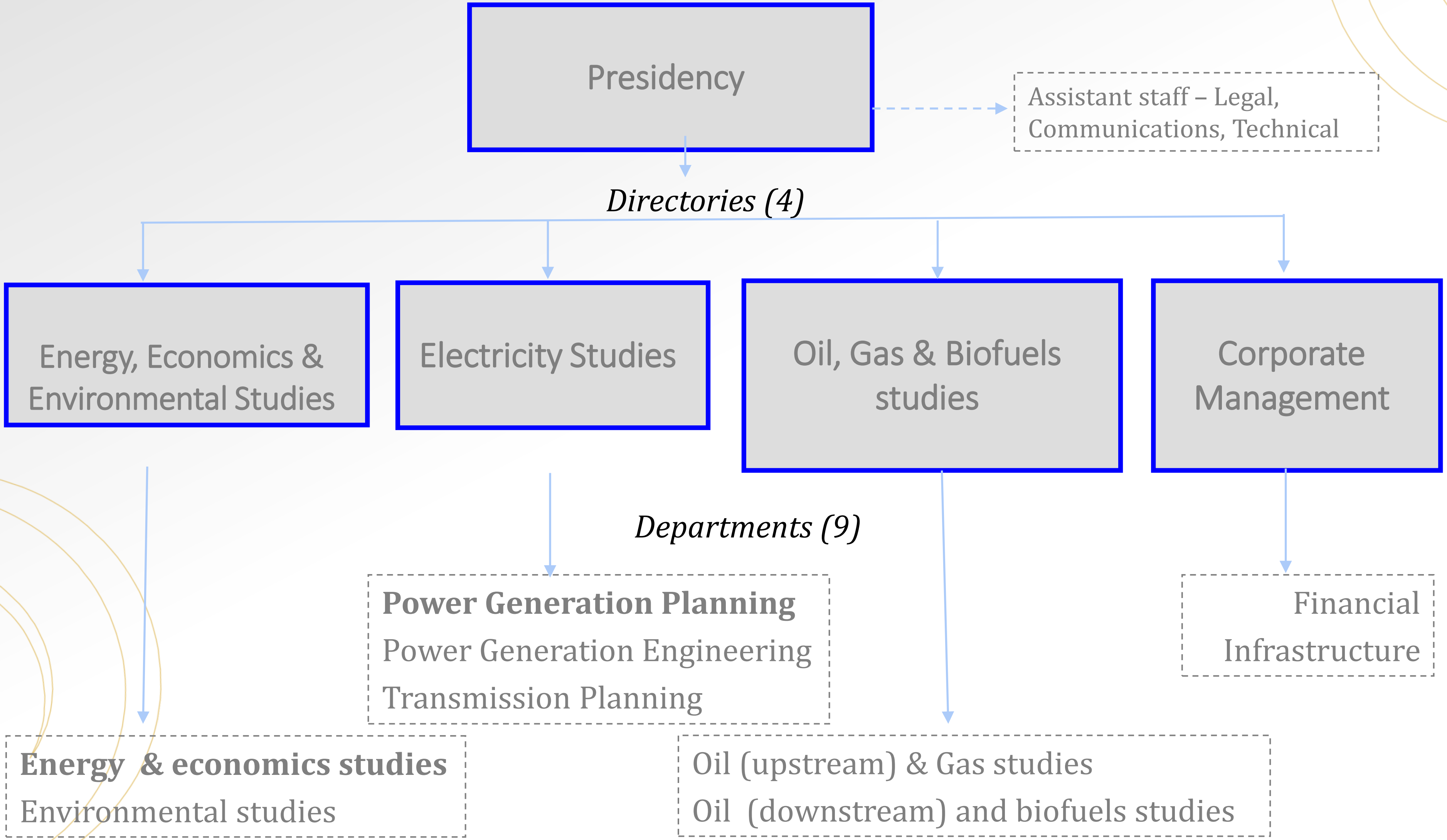
INSTITUTIONAL STRUCTURE OF BRAZILIAN ENERGY INDUSTRY



EPE – ENERGY RESEARCH OFFICE

- EPE is a 100% state-owned company, related to the Ministry of Mines and Energy (MME), created by Law # 10.847, of April 16th, 2004.
- EPE effectively started to work in January 2nd, **2005**.
- EPE is responsible for planning studies for the energy industry (power industry, oil & gas industry, renewable sources, nuclear power, energy efficiency).
- EPE studies give support to governmental policies settled by MME for the energy sector.

EPE – ORGANIZATIONAL STRUCTURE



EPE – MAIN ACTIVITIES

- National Energy Balance *(yearly issued)*
- **Energy Long Term Energy National Plan** *(currently under elaboration)*
- **Ten-year Expansion Plan** *(yearly issued*)
- Market analysis report *(monthly and quarterly)*
- Hydro Generation Inventory studies, including Integrated Environmental Evaluation of river basins
- Feasibility studies of Hydro Generation Projects
- **Energy auctions** – *registration, technical habilitation, assured energy calculation, evaluation of reference auction price (settled by MME)*
- Feasibility studies for Transmission System Expansion
- Transmission Expansion Plan – *supports ANEEL´s bidding process of transmission installations*
- Evaluation of Petroliferous Basins Potential
- Gas infrastructure expansion – *subsidies for ANP´s bidding process of gas pipelines installation*

Background on Brazilian Energy Industry and EPE

Brazil: 2016 statistics & PDE 2026

Gráfico 1.1.1 - Participação das Fontes na Capacidade Instalada
Chart 1.1.1 – Participation of Energy Sources in the Installed Capacity

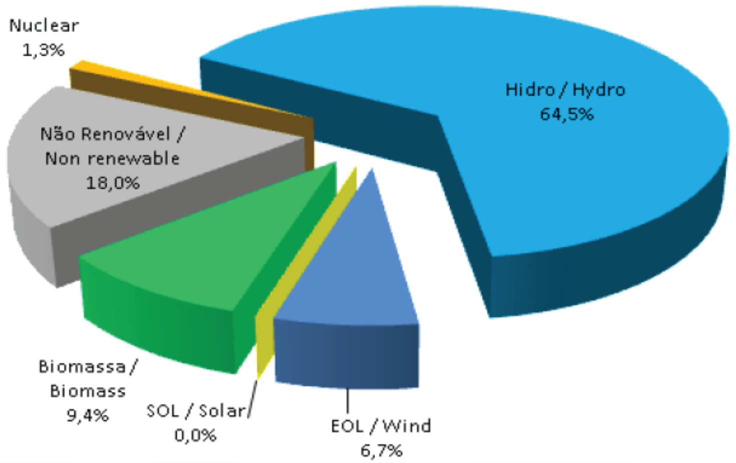
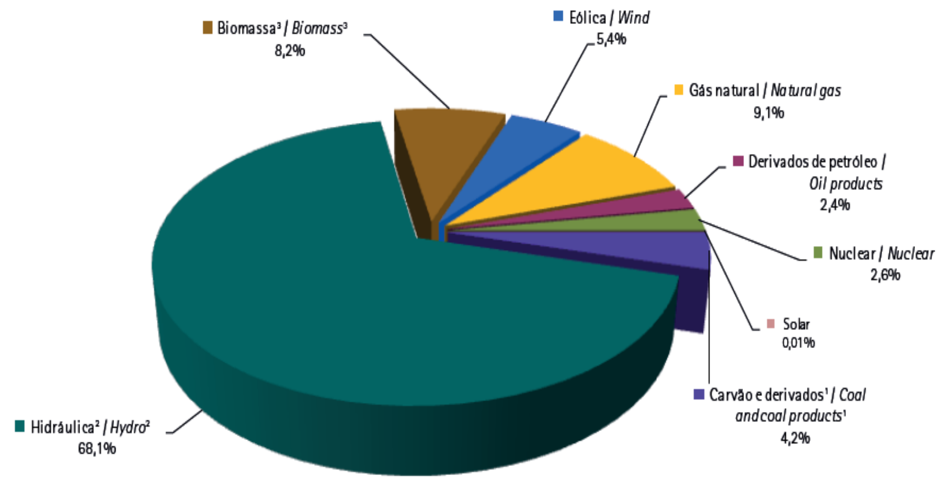


Gráfico 1.1 - Oferta Interna de Energia Elétrica por Fonte
Chart 1.1 – Domestic Electricity Supply by Source

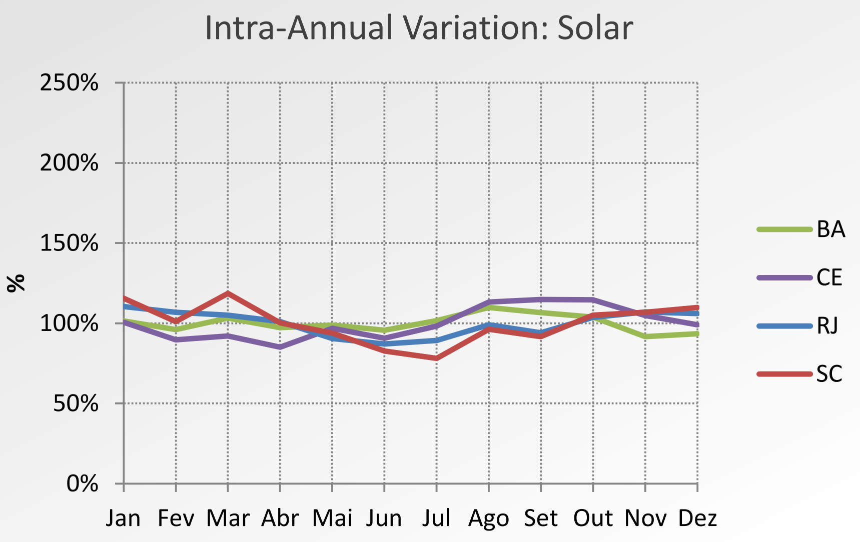


Source: EPE. Energy Balance 2017

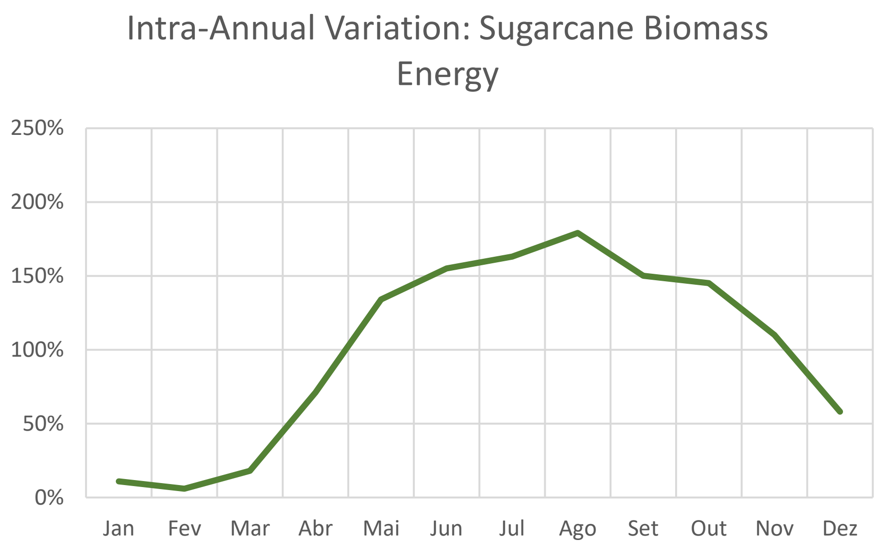
	2016	2021	2026	2016-2021		2021-2026		2016-2026	
				Incremento	%	Incremento	%	Incremento	%
Capacidade Instalada de Geração Elétrica no Sistema Interligado Nacional (6) (GW)	**148,4**	**179,4**	**212,5**	**31,0**	**21%**	**33,1**	**18%**	**64,1**	**43%**
Hidráulica (7)	96,7	109,0	110,5	12,3	13%	1,5	1%	13,8	14%
Nuclear	2,0	2,0	3,4	0,0	0%	1,4	71%	1,4	71%
Térmica (8)	21,0	23,4	23,2	2,5	12%	-0,2	-1%	2,3	11%
PCH+Biomassa+Eólica+Solar	28,7	45,0	63,2	16,2	56%	18,3	41%	34,5	120%
Alternativa Indicativa de Ponta	0,0	0,0	12,2	-	-	12,2	-	12,2	-

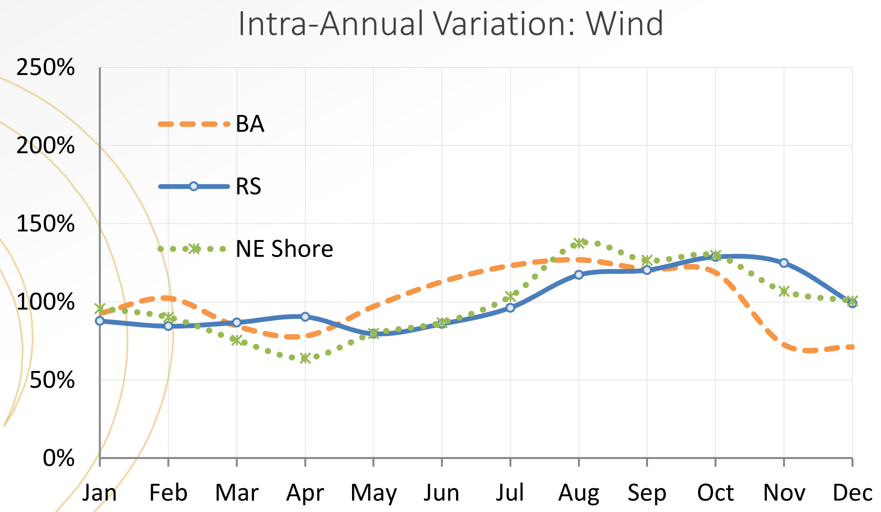
Source: PDE 2026

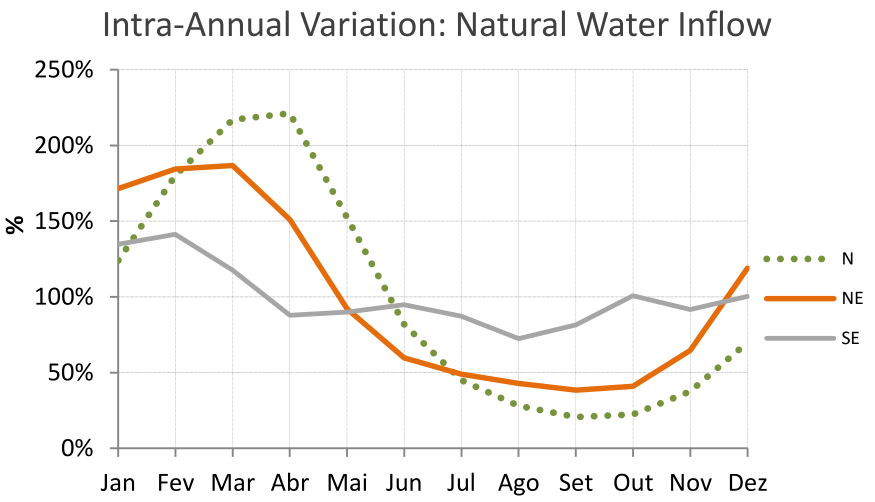
Renewables Production are Complementary



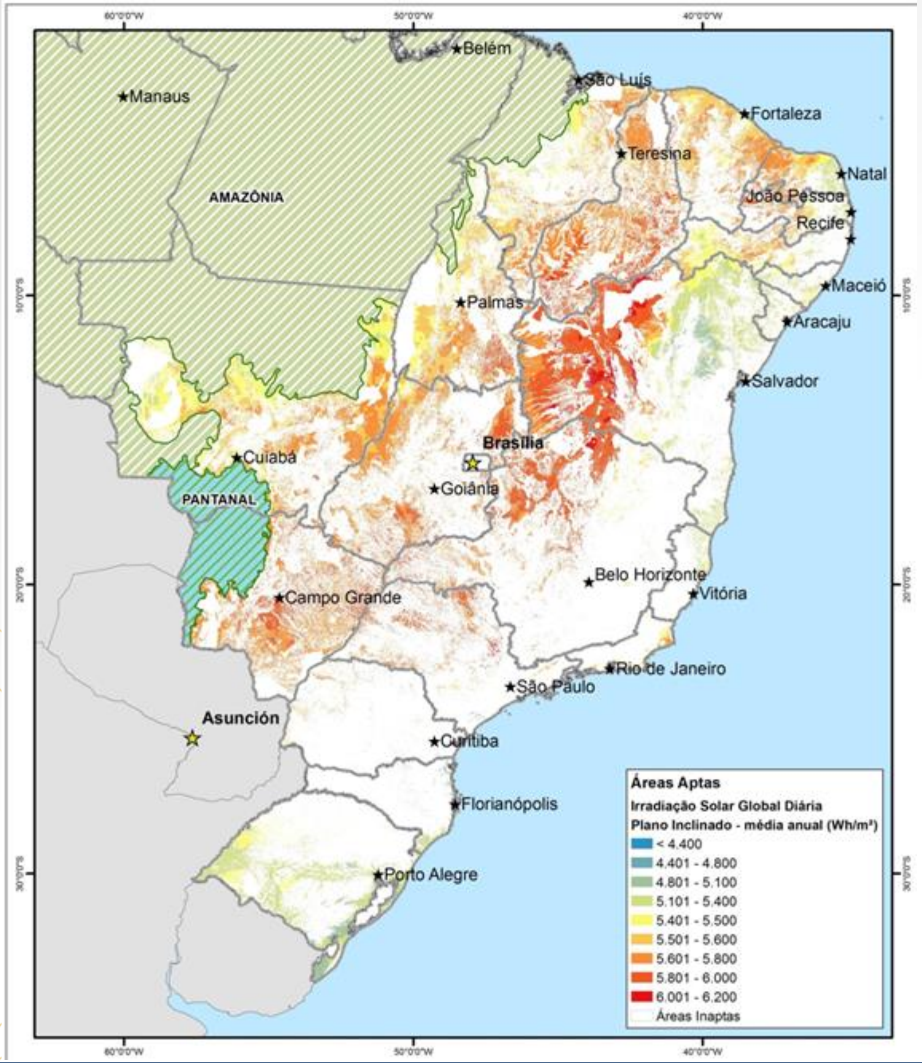
Reference: Made from PVWatts (NREL)





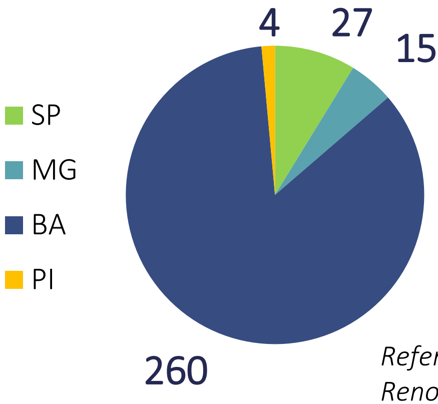


Brazil has an enormous PV technical potential



Excluding areas with native vegetation:

Irradiation (Wh/m².dia)	Technical Potential(GWp)
4400-4800	24
4800-5100	747
5100-5400	4.803
5400-5500	2.618
5500-5600	3.406
5600-5800	10.101
5800-6000	6.513
6000-6200	307



Reference: EPE – Book "Energia Renovável", 2016

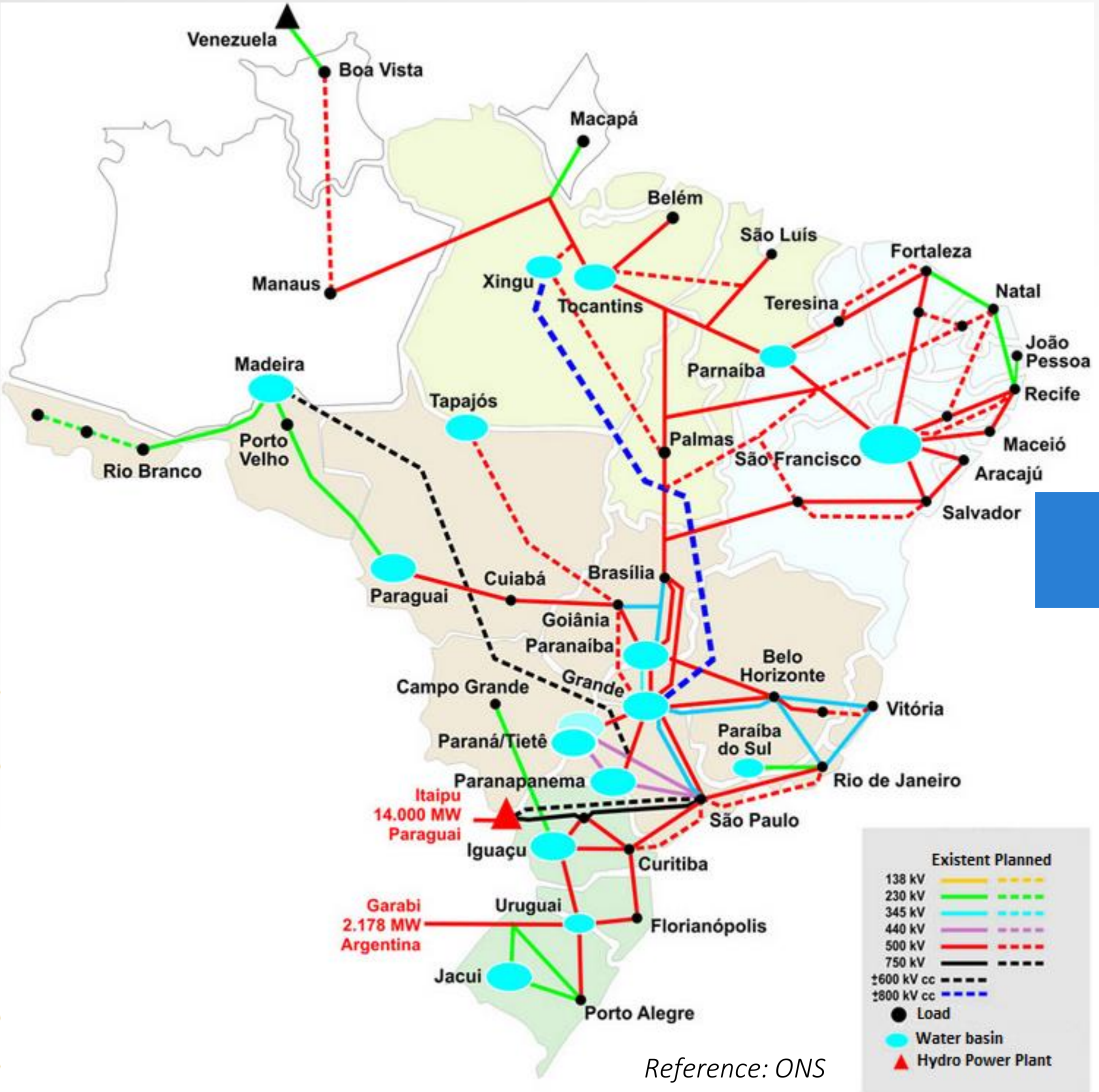
And Wind potential as well

Height	100 m		150 m	
Potential by State (>7m/s)	Capacity (MW)	Annual Energy (GWh)	Capacity (MW)	Annual Energy (GWh)
Alagoas 2008	0.6	1,340	-	-
Bahia 2013	70	273,500	195	766,500
Espírito Santo 2009	1.1	2,397	-	-
Minas Gerais 2010	39	92,076	-	-
Paraná 2007	3.4	9,386	-	-
Rio de Janeiro 2002	2.8	8,872	-	-
Rio Grande do Norte 2003	27	69,293	-	-
Rio Grande do Sul 2014	103	382,000	245	911,000
São Paulo 2012	0.6	1,753	-	-
Total	247	839,277	440	1,677,500

Reference: Prepared by EPE, multiple sources

Photo by Sam Forson

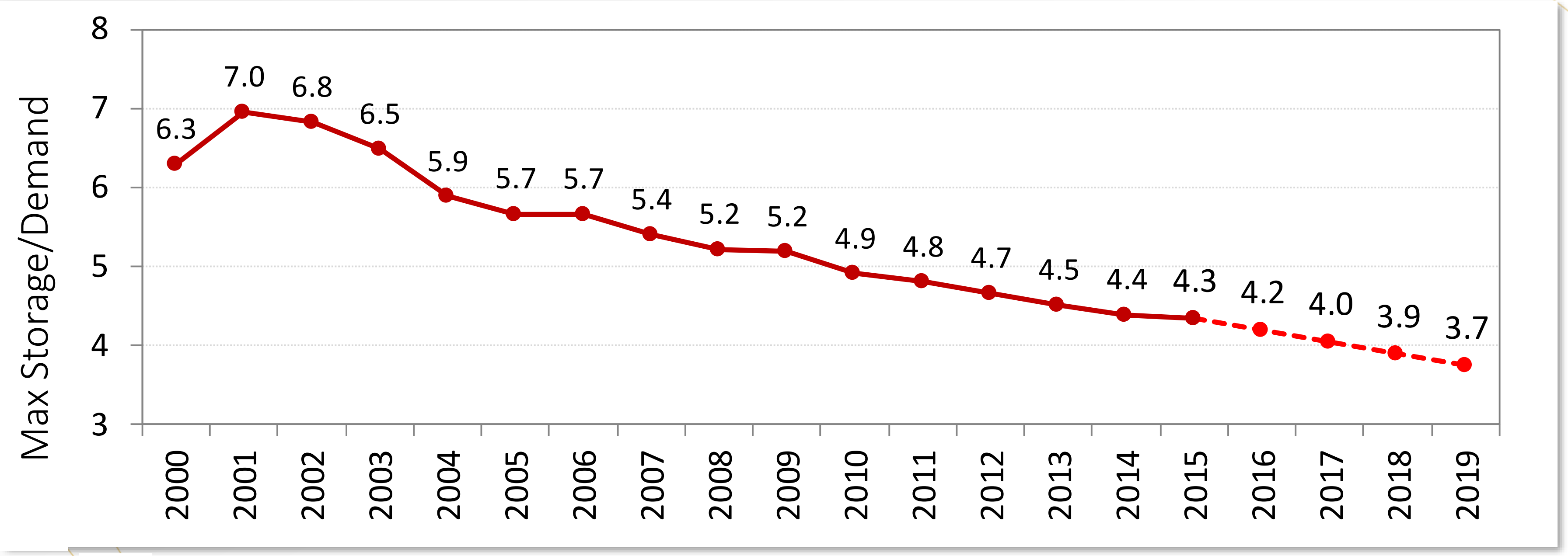
All hydropower are interconnected



Reference: ONS

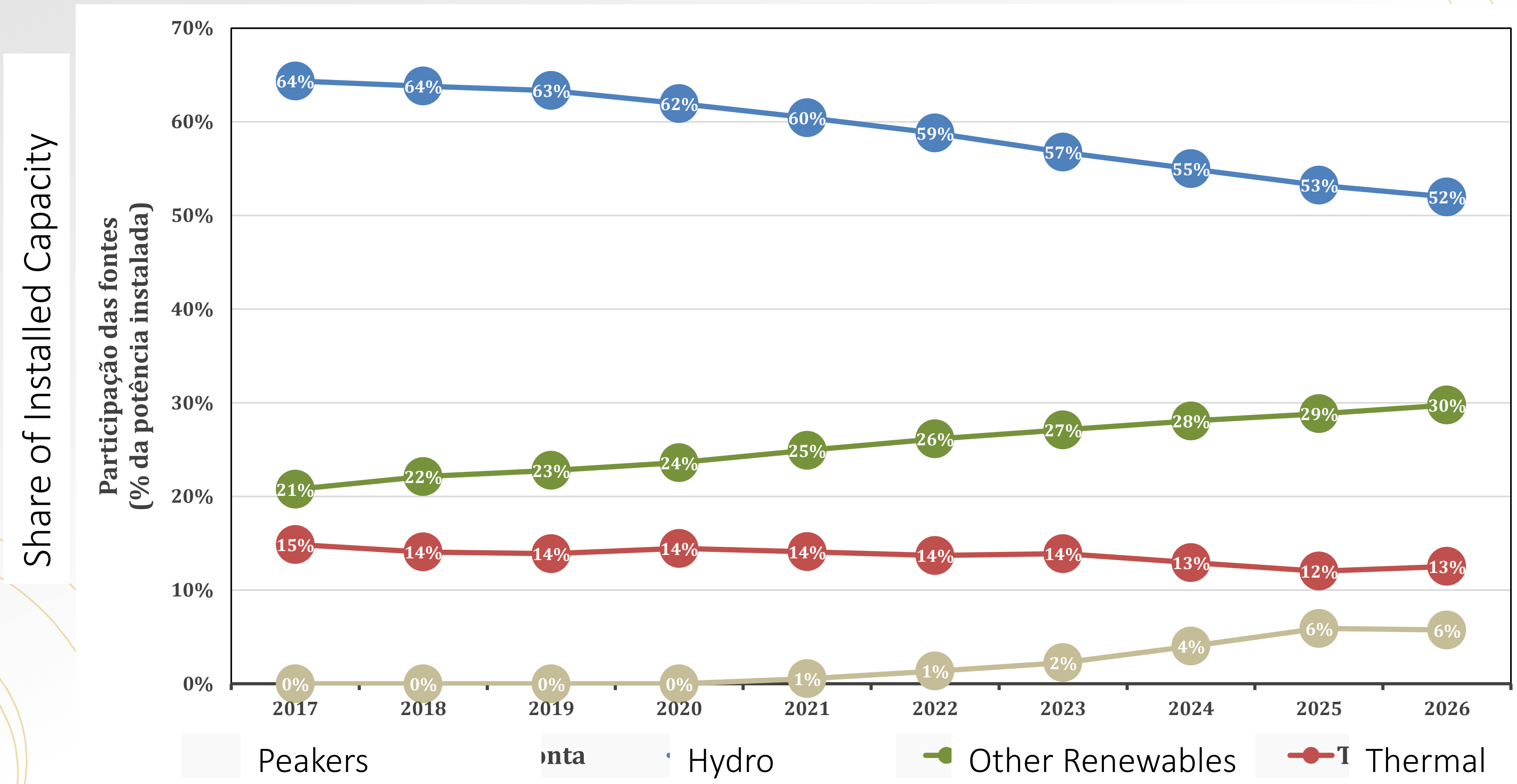
A great source of energy storage

Our relative storage capacity is decreasing.



Our energy mix has to change

PDE 2026: Summary of Results - Reference Case

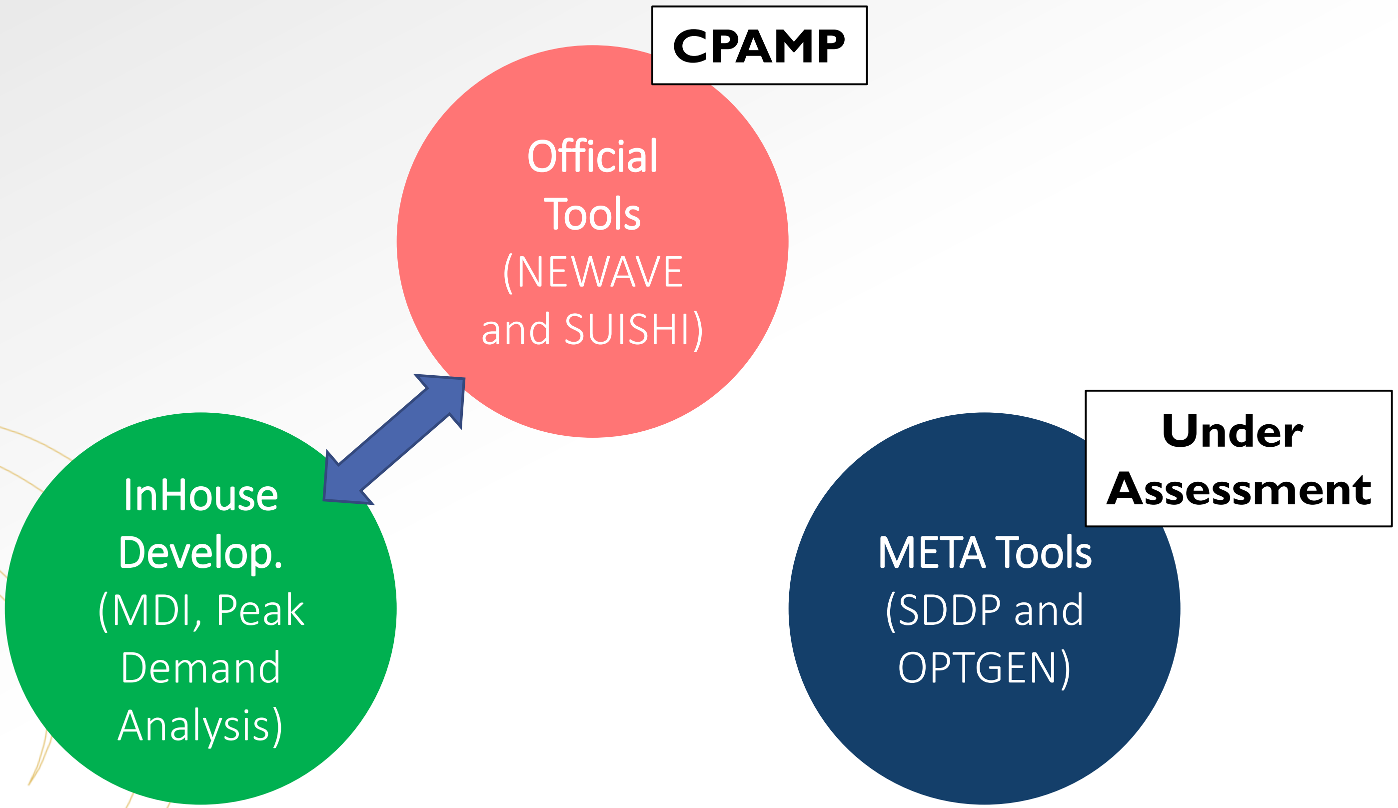


The diminishing share of hydroelectric and the increase of variable renewables requires solutions to meet peak demand.

Expansion Planning Modelling Tools

Sets of modelling tools

Actually EPE has 3 sets of tools for Energy Planning



Sets of modelling tools

Official Tools

- EPE is a member of CPAMP, responsible for monitoring the evolution of sector models
- NEWAVE, DECOMP, DESSEM, SUISHI
- Mid and short-term operation planning

InHouse Development

- Long-term planning with simplified operation model
- EPE is currently developing new features: integration between operation and expansion
- Peak demand and hourly supply check

Sets of modelling tools

META Tools

- In 2018, with resources from World Bank, EPE procured a new modelling package
- In November 2018, PSR and EPE signed a 3 years contract
- OPTGEN: long-term expansion planning
- SDDP: detailed operation (monthly or hourly resolution)
- Currently under assessment for future energy planning studies considering renewables, grid and gas sector constraints

Current Planning Metodology

Investment Decision Model

Computational model for investment support

Detailed Investment Problem

Simplified Operation

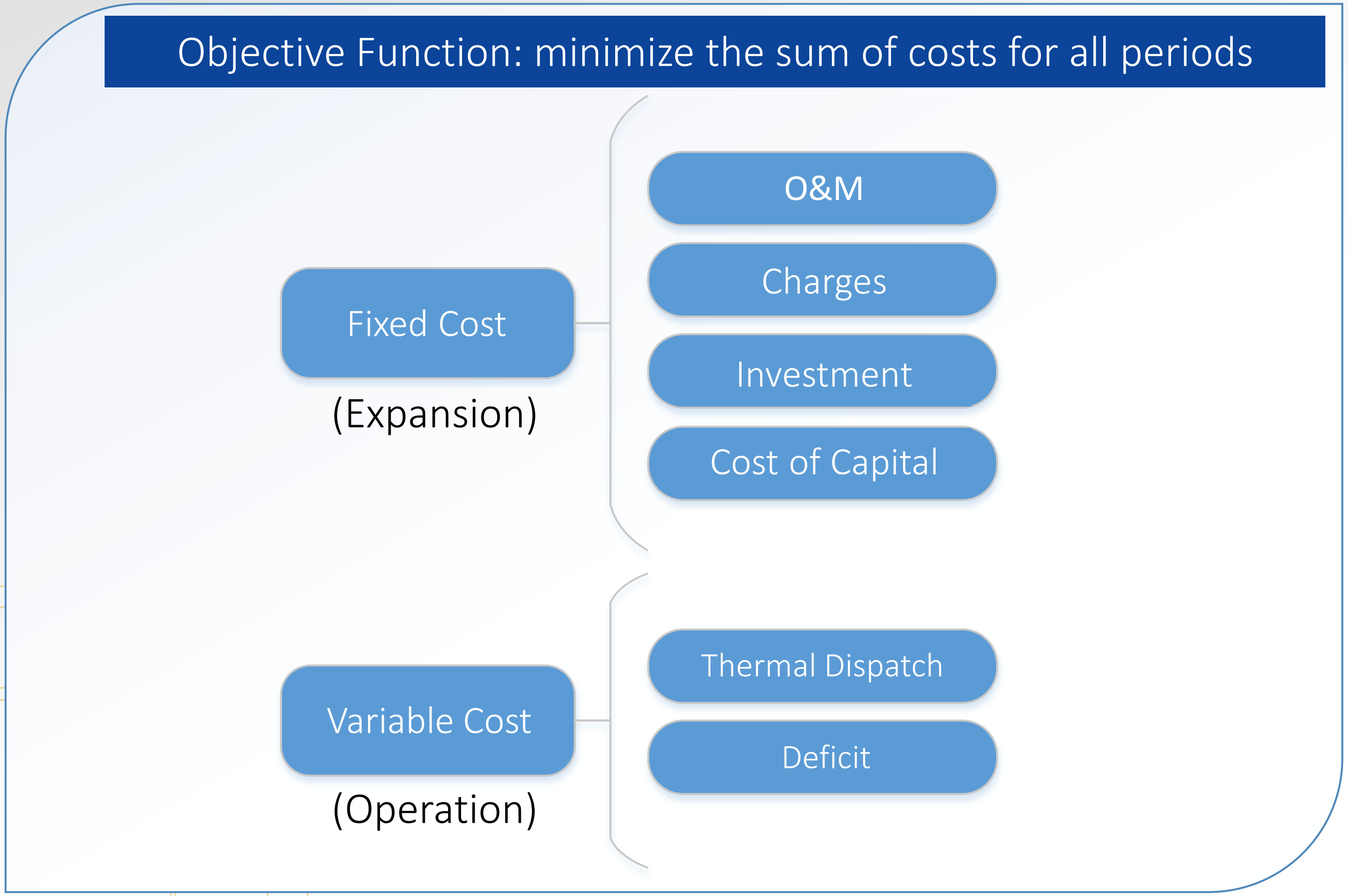
Expansion adjustments and operation simulation

Operation Simulation with Hydrothermal Model NEWAVE – developed by CEPEL):
Evaluates the operation of the system in order to detail future conditions of load balance.

Operation fine-tuning

Peak demand and hourly supply check

Investment Decision Model



Investment Decision Model: Main Characteristics

Power supply balance constraints

- Monthly or quarterly balance (depending on the timeframe), considering:
- Individualized generation scenarios for each Hydro Plant;
- Operation cost order dispatch for Thermal Power Plants;
- Production estimate for non dispatched generation (Wind, solar, biomass and small hydro)

Peak demand balance constraints

- Power capacity balance considering:
- Loss in Hydro Plants due to reservoir depletion;
- Unavailability of Thermal Power Plants;
- Hourly data for Wind Power Plants;
- Maximum Instantaneous Power and Operating Reserve.

Investment Decision Model: Main Characteristics

Hydro Conditions Representation

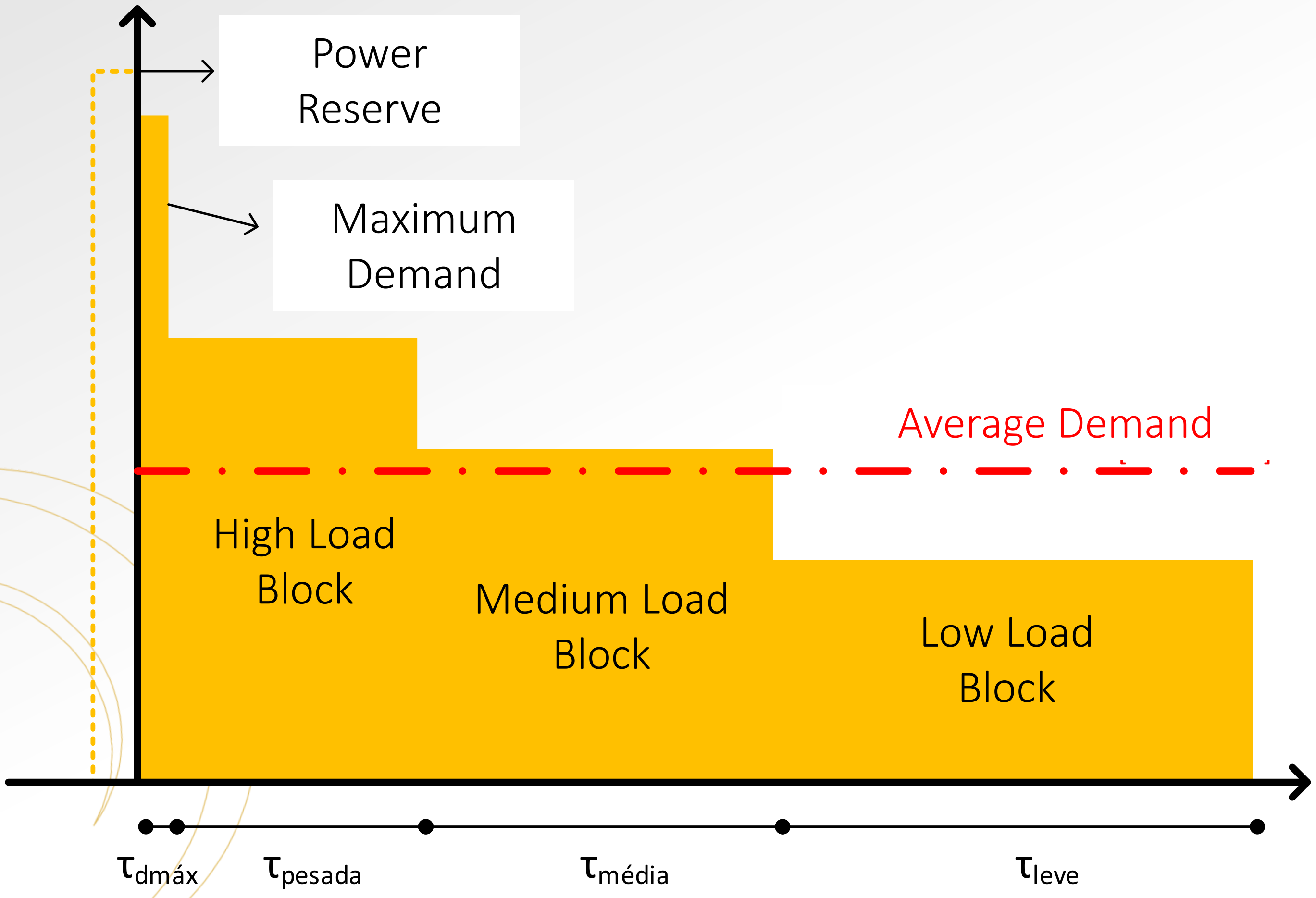
- These conditions are obtained from a HydroThermal chain of models
- Newave (to build depletion policy) and SUISHI (hydro individually simulation)
- Considers all available Hydro candidates
- 10 scenarios and each probability properly chosen
- Multi-period series of energy and power capacity
- Integer programming for Hydro Expansion

```
# Restricao de atendimento a demanda de energia em cac
def restAtendeDemanda (modelo, isis, iper, icen):
    # atendimento a demanda de energia
    return ((sum(modelo.prodTerm[term.nomeUsina,iper,i
            sum(modelo.interc[jsis,isis, iper,icen] fc
            - sum(modelo.interc[isis,jsis, iper,icen]
            + modelo.energiaRenovEx[isis,iper,icen] +
            + modelo.deficit[isis,iper,icen]) \
            + sum(modelo.capHidroNova[proj.nomeUsina,i
            + sum(modelo.capRenovCont[proj.nomeUsina,i
            + sum(modelo.capRenovInt[proj.nomeUsina,ip
            + sum(modelo.prodTermCont[proj.nomeUsina,i
            >= modelo.demanda[isis, iper, icen] + sum(
```

Other

- Open source, object oriented (Python)
- Data Input from MS Excel SpreadSheets
- Flexibility to introduce constraints

Investment Decision Model: Load Curve



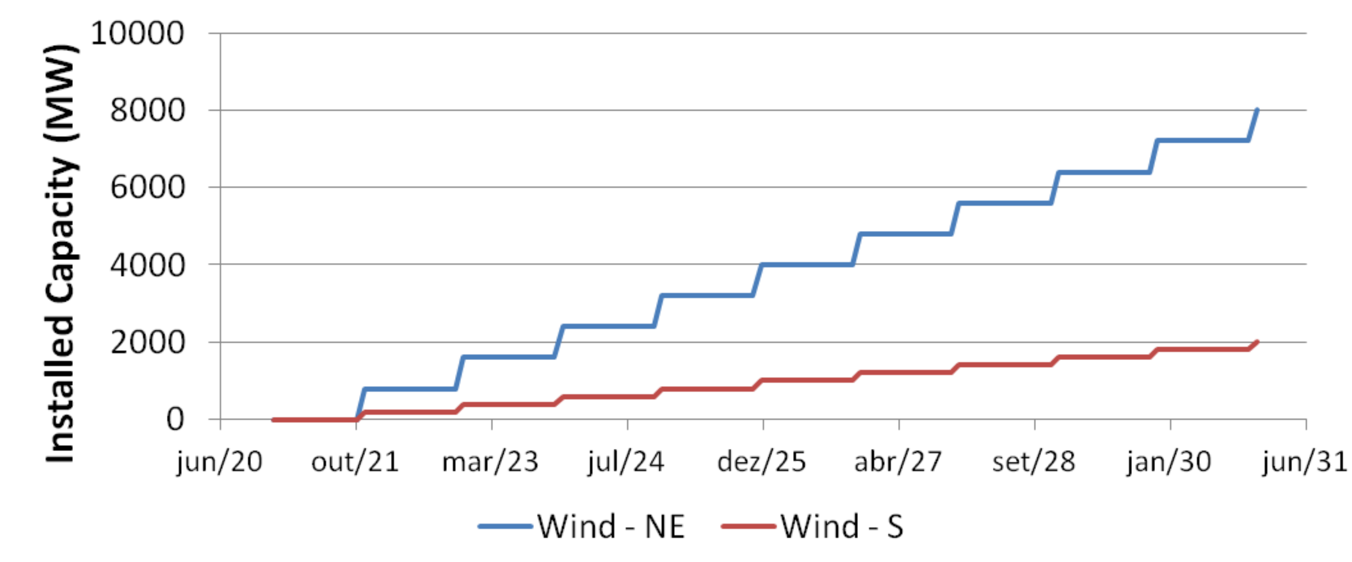
Investment Decision Model: Main Characteristics

Expansion by steps

- For certain sources model decides the total ammount of generation and equaly distributes along the horizon

Proportion betwen regions

- Historically , despite of higher capacity factor on Northeast region, many project on South region has been selected on Energy Auctions



Next Steps: Improve Representation

Algorithms

- Decomposition (Investment and Operation)
- Stochastic Optmization for reservoir operation (SDDP)
- Hourly representation (ramp-up/down, UC, etc.)

Computational Environment

- Julia Language
- Data Base Integration
- Parallel and Cloud Computing

```
# INicializa o objeto SDDP do Oscar
m = SDDPModel(
            risk_measure     = NestedAVaR(beta   = 0.5, lam
            cut_oracle       = DefaultCutOracle(), # metodo
            solver           = ClpSolver(),#GLPKSolverLP(),
            markov_transition= M,
            sense            = :Min, # problema de minimiza
            stages           = NPer, # numero de estagios
            objective_bound  = 0 # limite geral
                                    ) do sp, stage, markov

    UHEs = sin["UHE"]["usinas"]
    UTEs = sin["UTE"]["usinas"]
    r2u = sin["UHE"]["res"]
```

Detailed Operation Model

Main Characteristics

- Individual reservoir
- Commercial Solver (CPLEX: soon)

Innovations

- Parallelling strategies
- Inflows uncertaints by Markov Chain approach
- Different approach for "end of world effect"

Markov Chain

Faster implementation

- Don't need to estimate one model per hydro plant

Proposition

- 20 Markov states
- Historic inflows and observed transition probabilities

Estado
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

Dez -> Jan

Estado	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	32.9%	14.7%	10.5%	7.4%	5.4%	4.8%	4.1%	3.6%	2.6%	3.3%	1.9%	1.6%	1.6%	1.5%	1.6%	1.1%	1.1%	0.5%	0.9%	0.5%
2	18.6%	14.6%	10.9%	9.0%	6.4%	6.9%	4.3%	4.4%	4.5%	1.9%	2.9%	2.9%	2.2%	2.3%	1.7%	1.9%	1.2%	1.2%	0.9%	1.0%
3	13.4%	12.6%	8.1%	9.1%	7.4%	5.6%	7.0%	5.4%	4.0%	5.1%	3.4%	2.9%	3.6%	2.3%	2.3%	1.5%	1.6%	2.1%	0.8%	1.5%
4	9.2%	10.9%	10.0%	8.6%	7.7%	6.6%	7.5%	5.1%	4.4%	4.5%	3.9%	3.8%	3.5%	2.6%	2.4%	2.1%	1.9%	1.8%	1.8%	1.1%
5	6.5%	8.6%	8.9%	7.1%	8.6%	6.6%	6.4%	6.1%	6.4%	5.9%	4.5%	4.1%	3.7%	3.1%	2.8%	2.6%	3.5%	1.9%	1.7%	0.8%
6	4.9%	7.6%	8.7%	8.8%	7.9%	7.1%	6.6%	4.8%	6.4%	6.1%	4.8%	4.4%	4.5%	3.3%	3.4%	2.6%	2.4%	2.2%	1.9%	1.3%
7	3.6%	7.1%	6.9%	8.4%	6.9%	6.7%	7.0%	6.5%	5.4%	5.1%	4.9%	5.3%	5.0%	3.7%	3.9%	3.0%	3.1%	2.6%	2.3%	2.4%
8	3.4%	4.7%	7.4%	6.6%	7.4%	6.7%	6.8%	7.3%	7.0%	5.6%	5.4%	4.7%	4.6%	4.2%	3.8%	3.7%	3.4%	3.4%	2.2%	2.6%
9	1.9%	4.6%	6.1%	5.6%	6.6%	7.1%	5.9%	6.8%	7.4%	6.1%	5.3%	6.4%	4.6%	5.1%	3.9%	4.1%	3.9%	3.5%	2.3%	2.8%
10	1.8%	4.1%	5.4%	5.8%	5.7%	7.4%	5.2%	5.9%	7.6%	6.9%	6.4%	5.1%	5.1%	5.4%	4.6%	4.9%	4.2%	3.4%	3.3%	2.5%
11	1.3%	3.4%	3.4%	4.9%	6.4%	5.2%	7.8%	6.4%	5.4%	5.5%	6.7%	5.9%	5.3%	6.8%	5.1%	5.3%	5.2%	3.6%	3.7%	2.7%
12	1.0%	2.7%	3.8%	4.3%	5.3%	5.9%	5.3%	6.2%	5.6%	6.0%	6.5%	5.8%	6.1%	6.2%	4.8%	5.9%	5.8%	4.1%	4.5%	3.1%
13	0.6%	1.8%	2.1%	4.4%	4.6%	4.6%	5.4%	6.1%	5.1%	6.0%	7.1%	6.9%	6.4%	7.0%	5.8%	6.0%	5.1%	5.9%	6.1%	3.1%
14	0.4%	0.9%	2.2%	2.8%	4.1%	5.7%	4.9%	5.8%	4.9%	5.9%	6.8%	6.1%	7.4%	6.5%	6.0%	6.6%	6.4%	5.8%	5.4%	4.6%
15	0.2%	0.7%	1.8%	2.8%	3.0%	3.2%	3.9%	5.2%	5.3%	5.8%	7.4%	5.9%	6.6%	7.1%	8.9%	7.1%	7.1%	5.9%	7.0%	5.1%
16	0.1%	0.8%	1.6%	1.5%	2.2%	3.5%	3.7%	5.1%	6.2%	5.4%	5.6%	6.6%	6.4%	7.3%	7.7%	7.6%	7.9%	7.7%	6.7%	6.4%
17	0.0%	0.3%	1.0%	0.9%	1.6%	2.7%	3.1%	3.6%	4.4%	4.8%	5.7%	5.9%	7.2%	7.5%	8.6%	8.1%	8.1%	8.7%	9.4%	8.5%
18	0.0%	0.4%	0.2%	0.6%	1.4%	2.1%	2.9%	3.4%	3.7%	4.2%	5.3%	5.1%	6.3%	6.9%	8.6%	8.6%	8.4%	10.4%	9.9%	11.8%
19	0.0%	0.1%	0.1%	0.5%	0.7%	1.1%	1.1%	2.1%	3.7%	3.6%	4.1%	6.3%	6.1%	7.5%	7.5%	9.0%	9.9%	12.0%	13.4%	11.9%
20	0.0%	0.0%	0.1%	0.1%	0.3%	0.1%	0.3%	0.8%	1.0%	1.6%	2.5%	3.7%	3.2%	4.6%	7.2%	7.8%	10.7%	13.4%	16.5%	25.9%

"End of the World Effect"

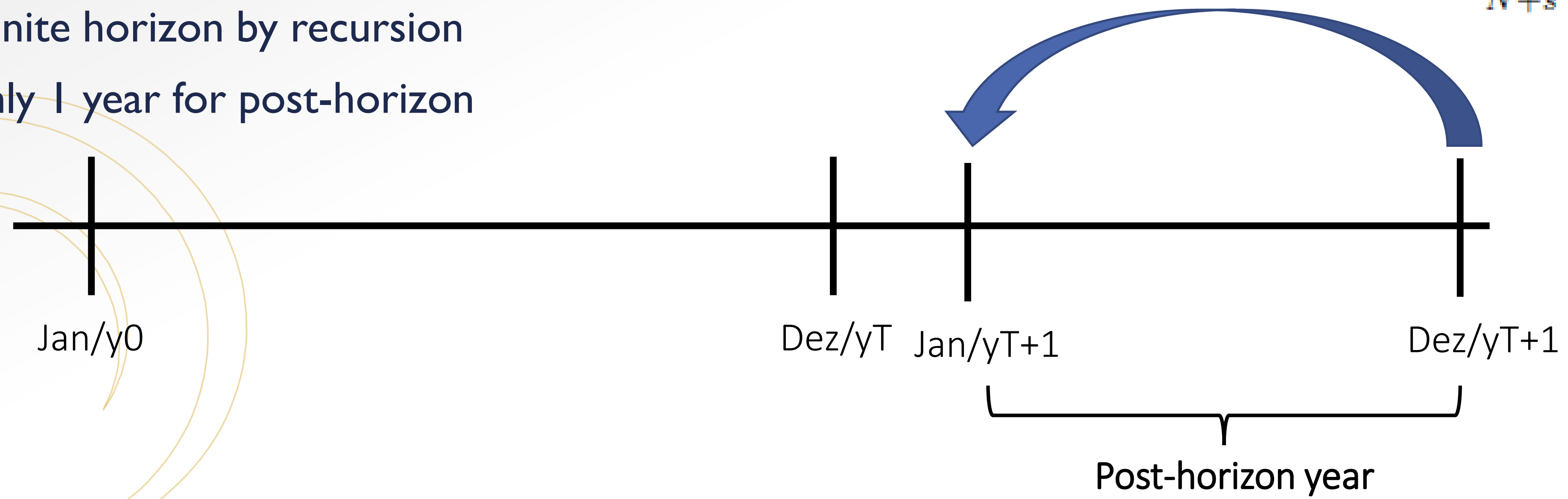
What does it mean?

- In the last stage, stored water has zero value
- Traditional solution: append 3-5 year in the horizon end

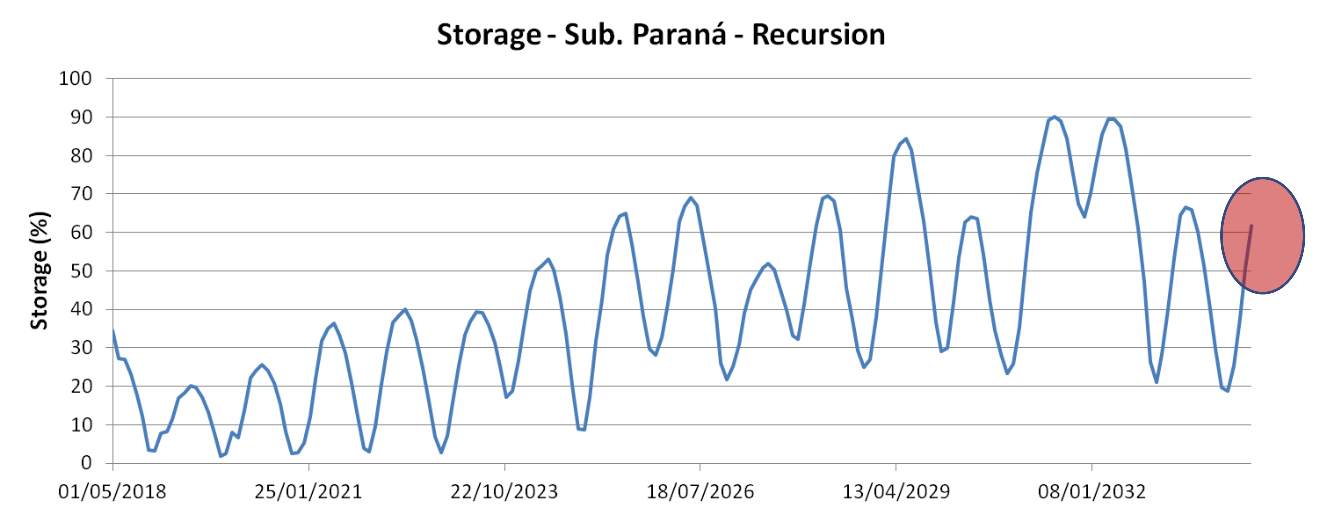
New Approach

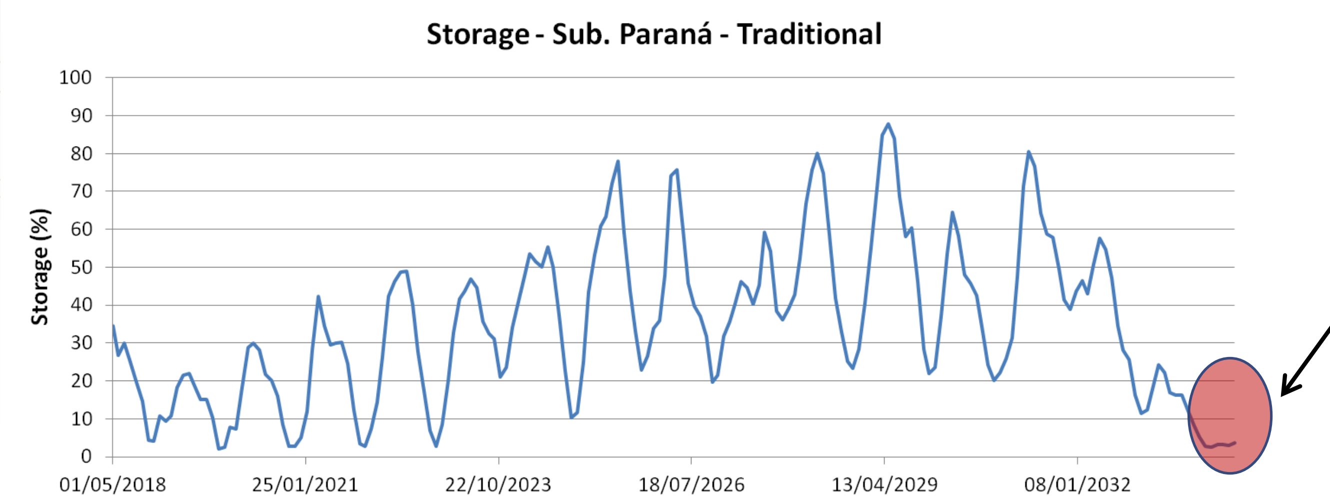
- Infinite horizon by recursion
- Only 1 year for post-horizon

$$\alpha_{N+s}^{i+1} \equiv \alpha_N^i$$



“End of the World Effect”: Results





End of the world Effect

Thank you