APPLIED ANALYTICS TO IDENTIFY POTENTIAL OPPORTUNITIES FOR INVESTMENT IN HYDRO POWER

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Presentation delivered at

Overview

- A Little About myself…
- Introduction
- Climate Effects in Energy Systems
  - Problem's characteristics
  - Water-Energy Nexus
  - Energy Assessment and Stochastic Programming
  - Investment Decision Analysis
  - Identification of potential investments in hydro
- Final Comments

A Little About myself…

- Born in Mogi Mirim, SP – Brazil (1982)
- Professional Preparation
  - B.S. in EE (2005)
  - M.Sc. in EE (2007)
  - Ph.D. in ORIE (2011)
- Appointments
  - Assoc. Consultant and Partner (2006 – 2013)
  - Asst. Professor (2013)
  - Postdoc Researcher (2015)
  - Res. Asst. Professor (2016)

My research focus on applied decision-making and analytics with focus on optimization (stochastic, linear, integer, dynamic and large scale), simulation, clustering methods, benchmarking and decision analysis. Hands-on experience solving problems in sustainable systems, renewable energy, climate influence in the water-energy nexus, scheduling, planning, and transportation

Introduction

Introduction

- **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

Climate Effects in Energy Systems

Climate Impacts in Electricity Generation

Climate Change Evaporates Part of China's Hydropower

The nation's hydropower production dropped by 25 percent thanks to an unusual drop in river flow

By Coco Liu and ClimateWire | Tuesday, November 8, 2011 | 28 comments

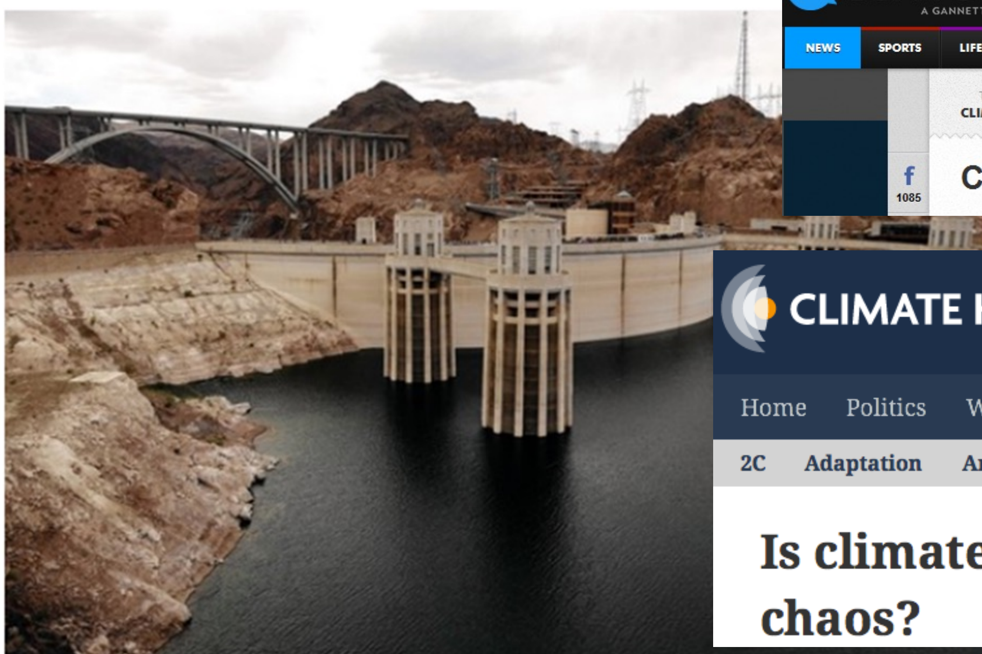
THE WALL STREET JOURNAL. | U.S.

U.S. NEWS

Decade of Drought Threatens West

By JIM CARLTON CONNECT

Aug. 16, 2013 7:10 p.m. ET



The Hoover Dam at Lake Mead. *Associated Press*

California's Hydroelectricity Production Is Vulnerable to Climate Change

Kaveh Madani, former researcher at UC Riverside, says hydropower stations would generate less electricity in summer under climate warming

By Iqbal Pittalwala On AUGUST 6, 2012 SHARE THIS ARTICLE:

USA TODAY A GANNETT COMPANY

NEWS SPORTS LIFE MONEY TECH TRAVEL OPINION 41° SUBSCRIBE

This story is part of CLIMATE CHANGE | Diseases on the move because of climate change | A deadly parasite moving north | Alaska sinks as climate change thaws permafrost

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Climate change will disrupt energy supplies, DOE warns

CLIMATE HOME News TV Magazine

Home Politics World Energy Finance Cities Technology Science Opinion

2C Adaptation Antarctic Arctic Corals Forests Glaciers Research Nature Water

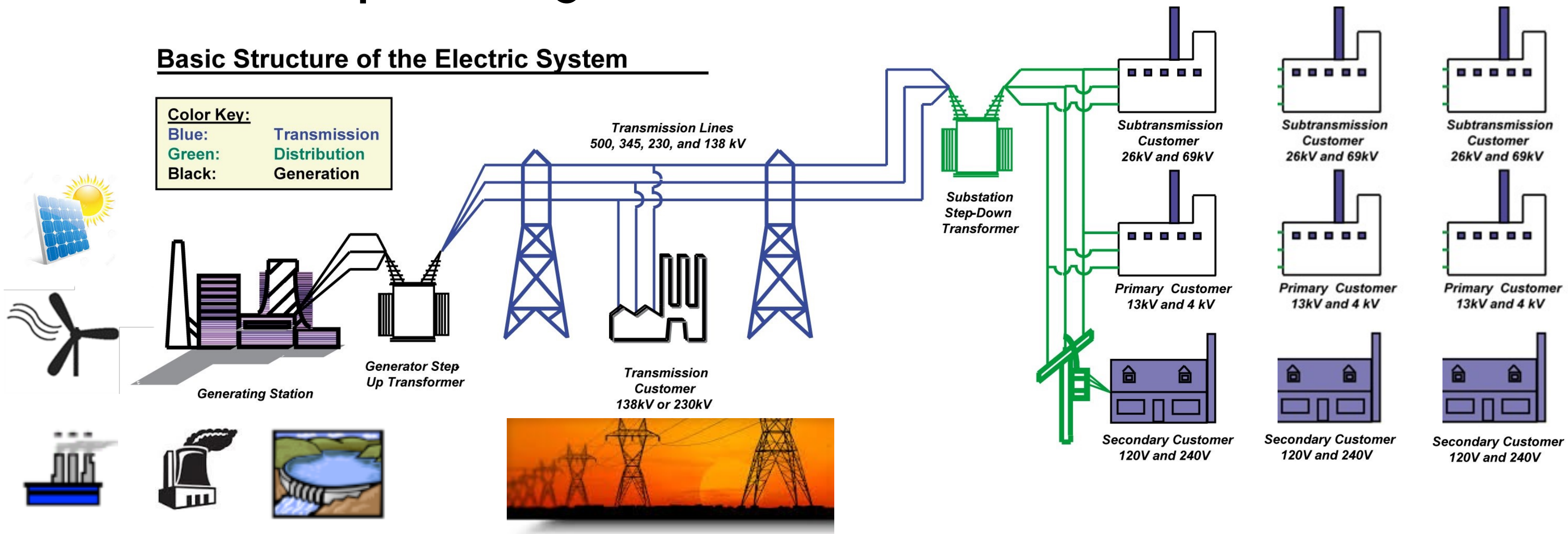
Is climate change driving Brazil's drought chaos?

Climate Change and the Future

- Strong evidences related to climate change have emerged over the years
- In this context it is necessary to understand the importance to consider this information in different spheres:
  - Agriculture
  - Water supply
  - **Electricity production**
  - Biodiversity
  - Society as a whole
- Need to plan for the future

Power Generation Planning

- Generally, planning studies for capacity expansion in terms of power generation do not consider climate



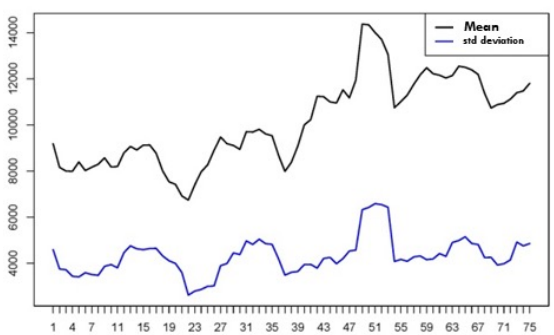
- Basically the system planner looks how the load will likely to grow in the future and make decisions

Climate Change – Basics

- First of all what is climate change?

“Climate change is a ***change in the statistical distribution of weather patterns*** *when that change lasts for an* ***extended period of time****”* **(Wikipedia, 2016)**

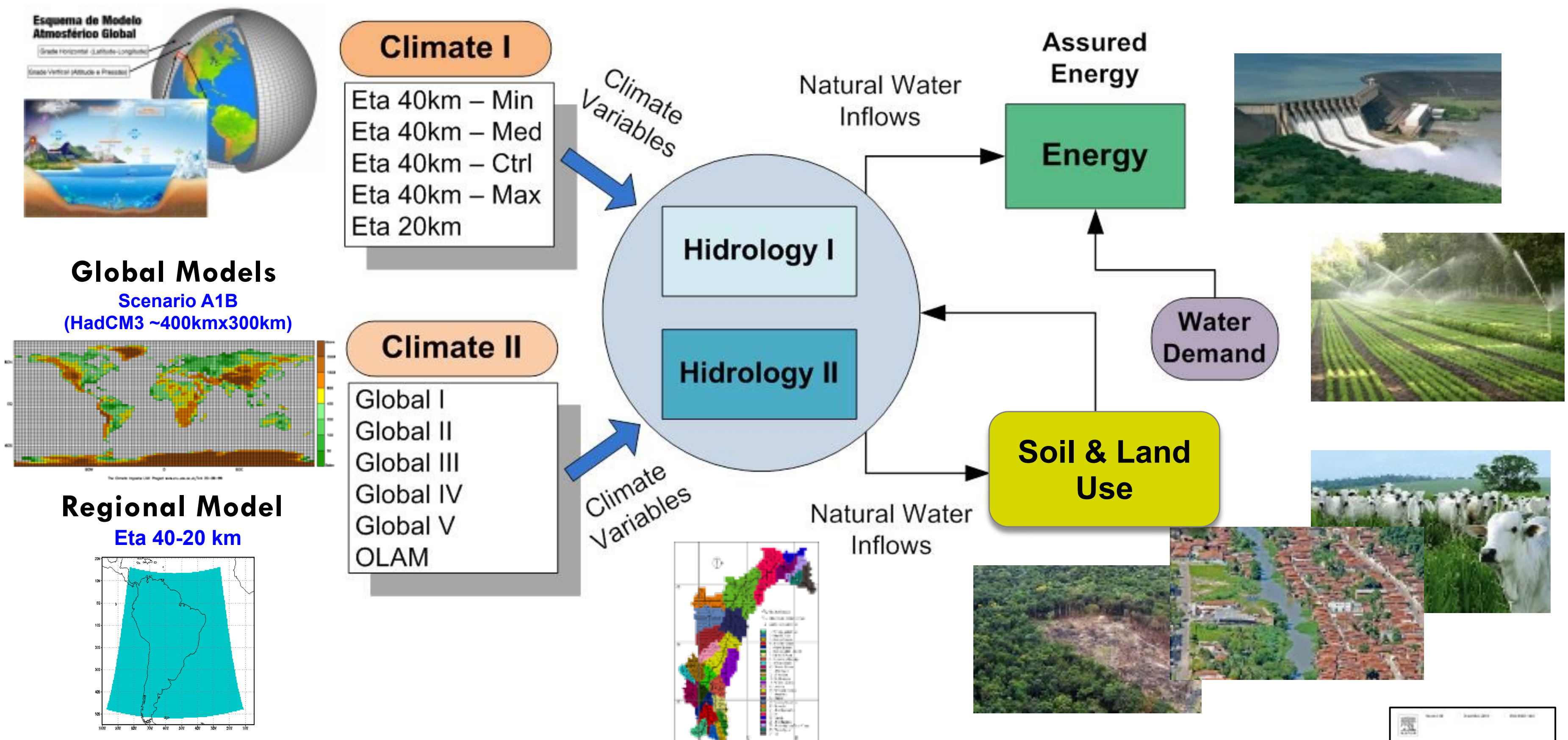
“Scientific evidence for warming of the climate system is unequivocal”



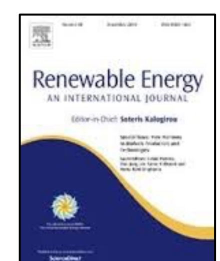
4th IPCC report ← **(NASA, 2016)**

- Climate change may modify our knowledge about the system

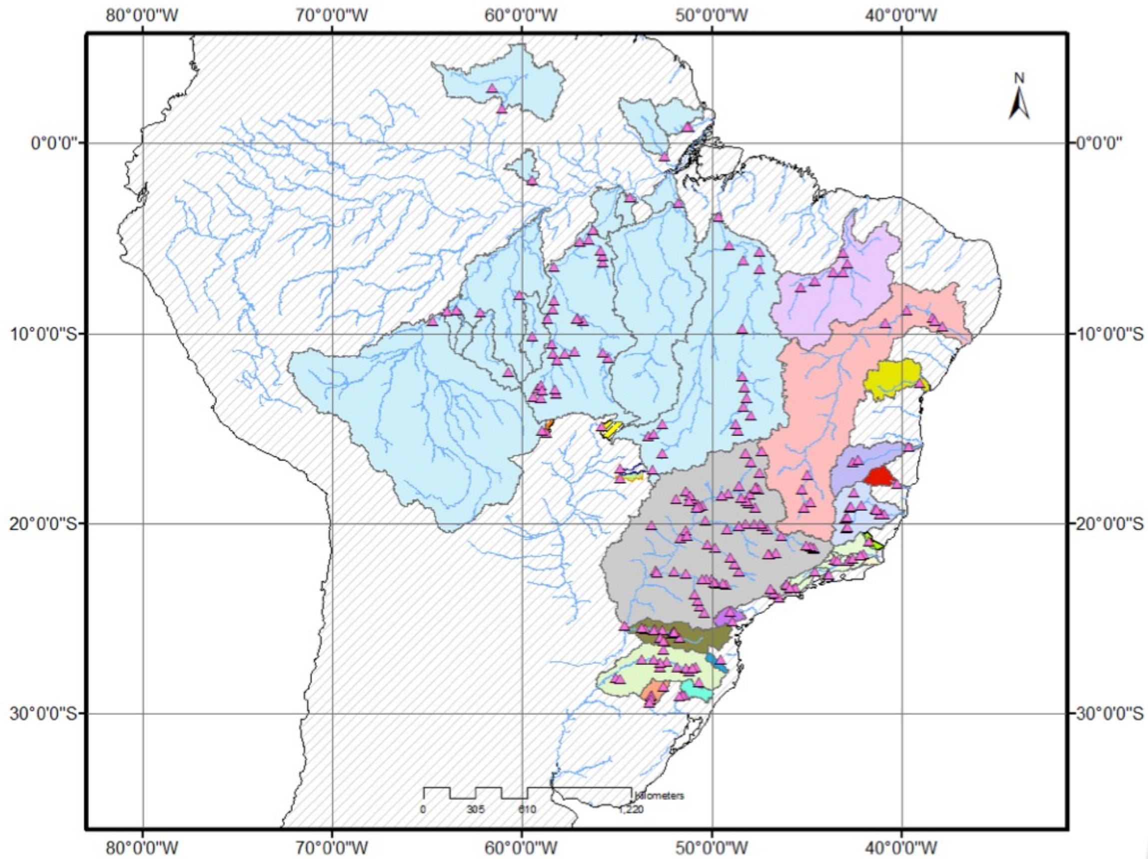
Water-Energy Nexus



de Queiroz, A.R., Lima, L.M.M., Lima, J.W.M., Silva, B.C., Scianni, L.A., (2016) Climate Change Impacts in the Energy Supply of the Brazilian Hydro-dominant Power System, Renewable Energy, 99: 379-389



Brazilian Interconnected Power System



Existing Generation Park (EGP)

157 Hydro Plants

76% of the power generation installed capacity (110 GW)

Future Generation Park (FGP)

245 Hydro Plants

67% of the power generation installed capacity (170 GW)

Most of the Power Generation Expansion in the North Region

Action Items

AI01. Identify if there are **evidence of climate change** effects in the water inflows patterns

AI02. Assess the **potential impacts in hydro** generation under different climate scenarios

AI03. Analyze possible **attractive investment opportunities** for hydro generation

AI01: Climate Effects in Water Inflows

- We want to evaluate potential trends positive (or negative) in water inflows
- We use monthly data series from 1931 up to 2012
- We run different tests to obtain our results

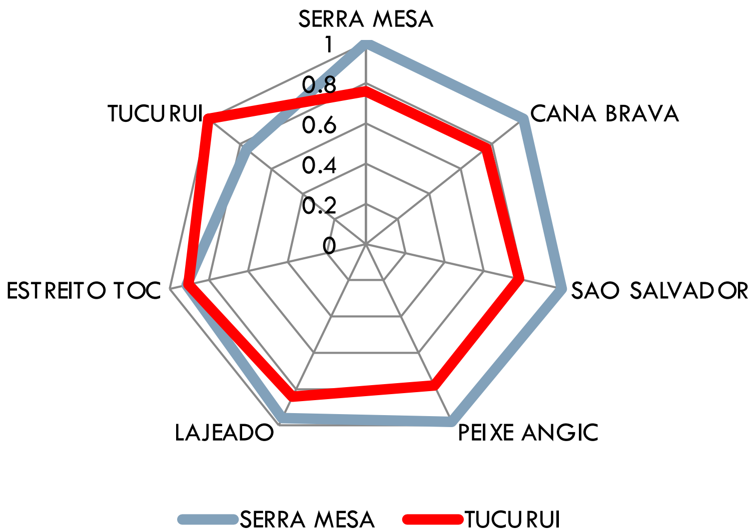
Basins Characteristics

Largest basins of the system

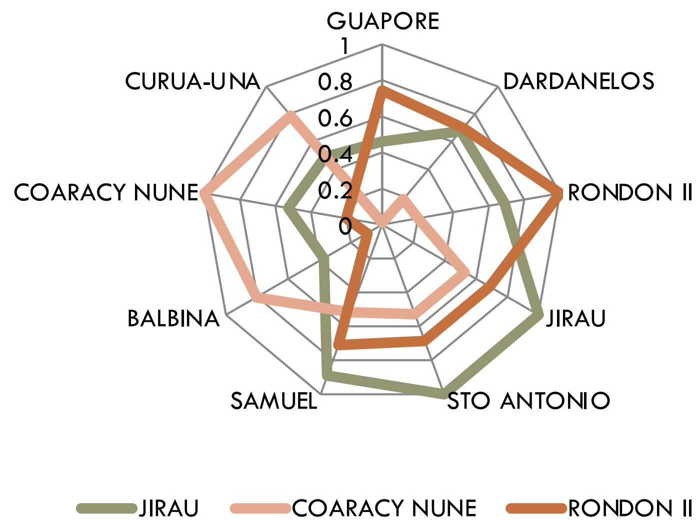
	CAPACITY [MW]	% of the Total	Avg. Inflows [m³/s]	% of the Total
Amazonas	7480	8.1%	21408	41.0%
Tocantins	12780	13.8%	10980	21.0%
Atl. Norte/ Atl. Nordeste/ Parnaíba	237	0.3%	463	0.9%
São Francisco	10577	11.4%	2746	5.3%
Atlântico Leste	1030	1.1%	586	1.1%
Paraná / Paraguai	49237	53.2%	12119	23.2%
Uruguai / Atlântico Sul	7337	7.9%	2318	4.4%
Atlântico Sudeste	3789	4.1%	1608	3.1%

Stationarity Analysis

- The **water inflows series** for hydro plants inside the same basin **are** strongly **correlated**
- For a single basin, we evaluate the stationarity hypotesis for the "representative(s)" hydro plant(s)
- We aim to identify if such series are influenced by time
  - **Tocantins Basin**

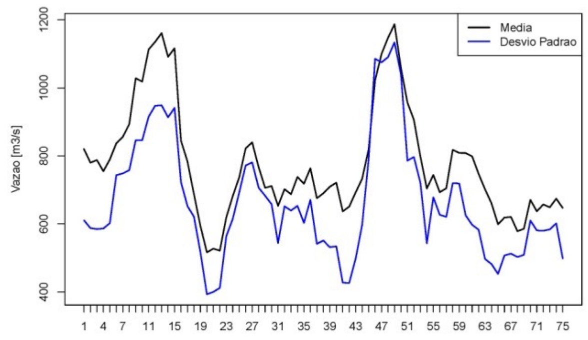


  - **Amazonas Basin**

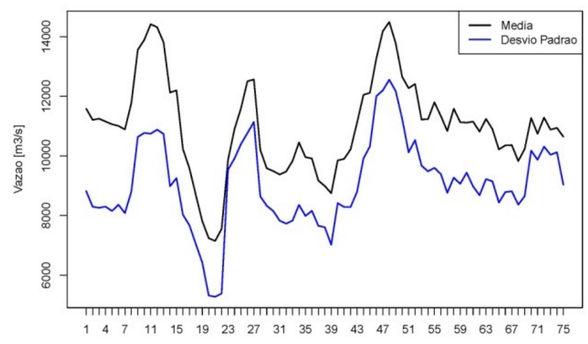


Mean and Standard Deviation Analysis

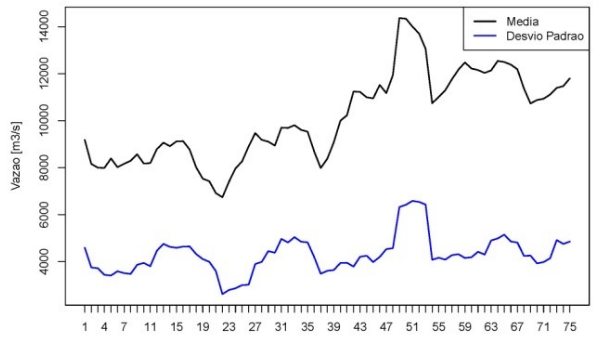
HPP Serra da Mesa



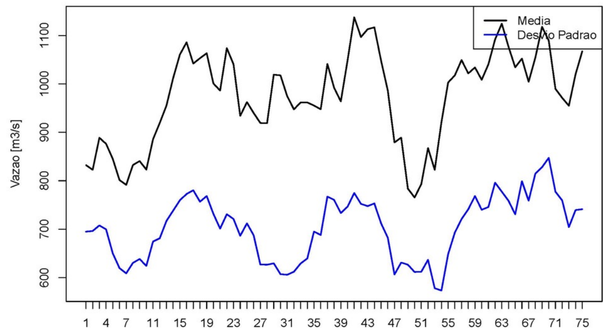
HPP Tucuruí



HPP Itaipu



HPP Coaracy Nunes



Stationarity – Annual Analysis

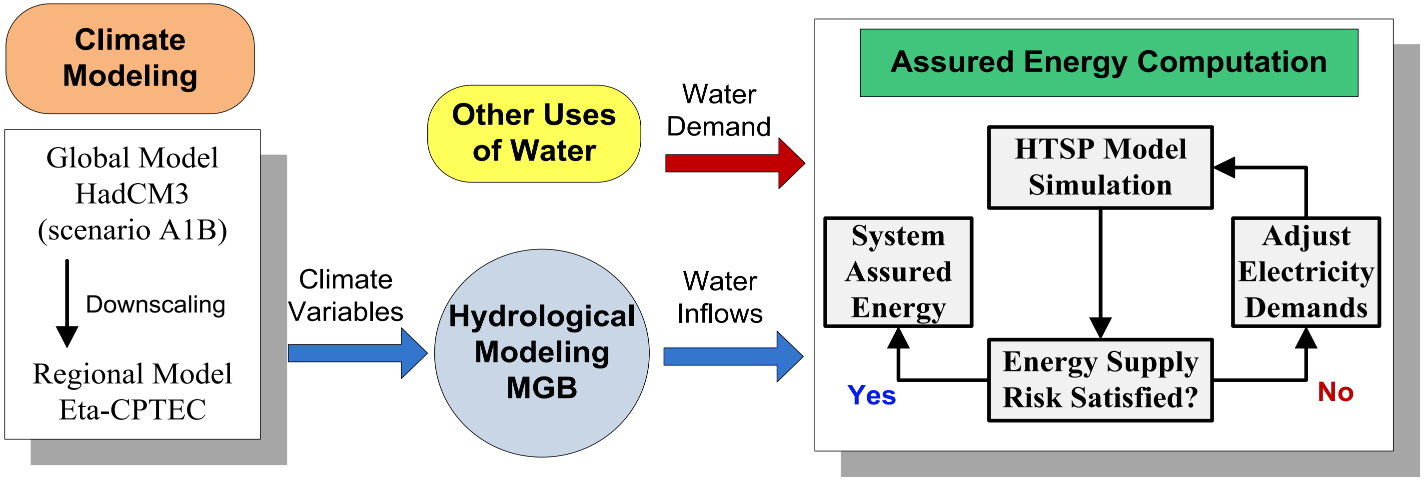
- We test stationarity in the data using:
  - **Mann Kendall**
  - **Spearman Correlation**
- The hypotesis test was designed as:
  - **Ho: no trend**
  - **Ha: there is a trend** (either + or -)
  - Reject **Ho** when p-value <= 0

Hydro Plant	Mann Kendall	Spearman Correlation
HPP JIRAU	Stationary	Stationary
HPP RONDON II	Decrease	Decrease
HPP COARACY NUNES	Increase	Increase
HPP TUCURUI	Stationary	Stationary
HPP SERRA MESA	Stationary	Stationary
HPP SOBRADINHO	Decrease	Decrease
HPP ITAPEBI	Stationary	Stationary
HPP P. CAVALO	Stationary	Stationary
HPP AIMORÉS	Decrease	Decrease
HPP PARAIBUNA	Stationary	Stationary
HPP FURNAS	Stationary	Stationary
HPP BARRA BONITA	Increase	Increase
HPP JUPIA	Increase	Increase
HPP ITAIPU	Increase	Increase
HPP G.B. MUNHOZ	Increase	Increase
HPP P. PEDRA	Increase	Increase

There are trends in these series that maybe explained by climate change

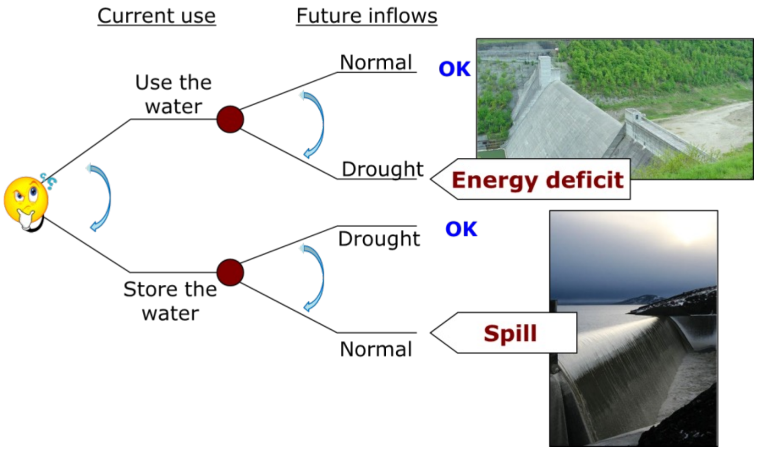
AI02: Potential Impacts in Hydro

- Given this context, how the system may behave in the future if we continue to experience changes in climate?
- We designed a **simulation-optimization framework** to investigate such question and support decision-making
- A stochastic model for the **hydro-thermal scheduling problem** (HTSP) is used to identify the system's potential (assured energy)



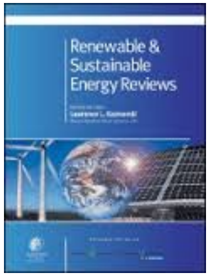
Stochastic Hydro-thermal Coordination

- 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



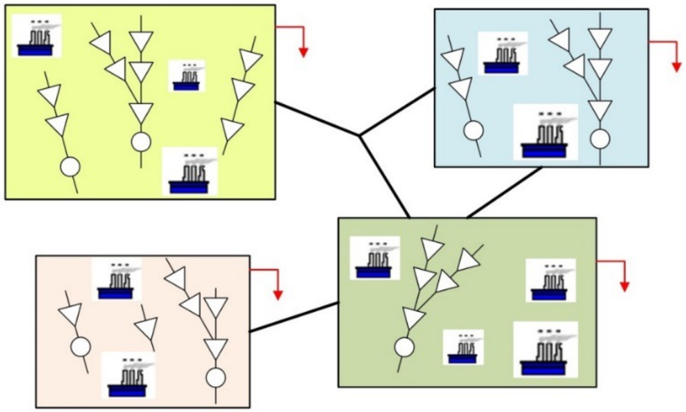
- Basic economic criterion
  - **Minimize operational costs** (present + expected future)
- Usually modeled as Multi-stage Stochastic Linear Program (SLP-*t*)

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



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

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

Water Balance

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

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

$$\underline{x_i^t} \le x_i^t \le \overline{x}_i^t \qquad \forall i \in I$$

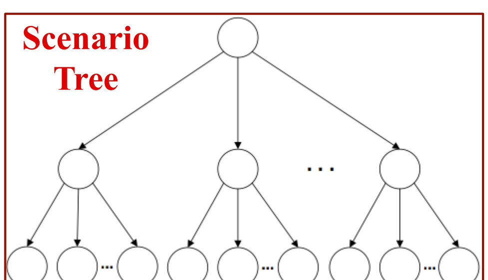
$$0 \le GH_i^t \le \overline{GH_i^t} \qquad \forall i \in I$$

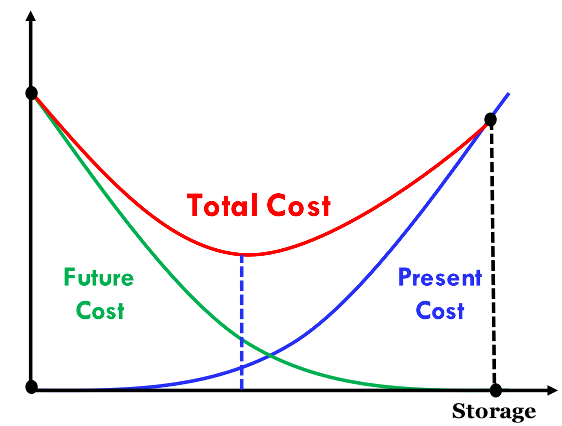
$$0 \le S_i^t \qquad \forall i \in I$$

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

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

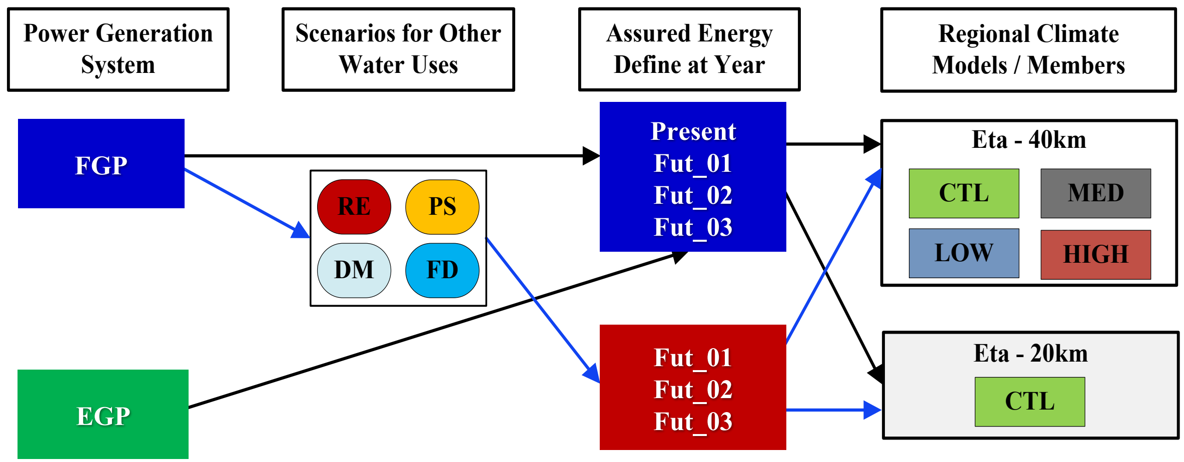
$$0 \le F_{r\,r'}^t \le \overline{F_{r\,r'}^t} \qquad \forall (r, r') \in R$$

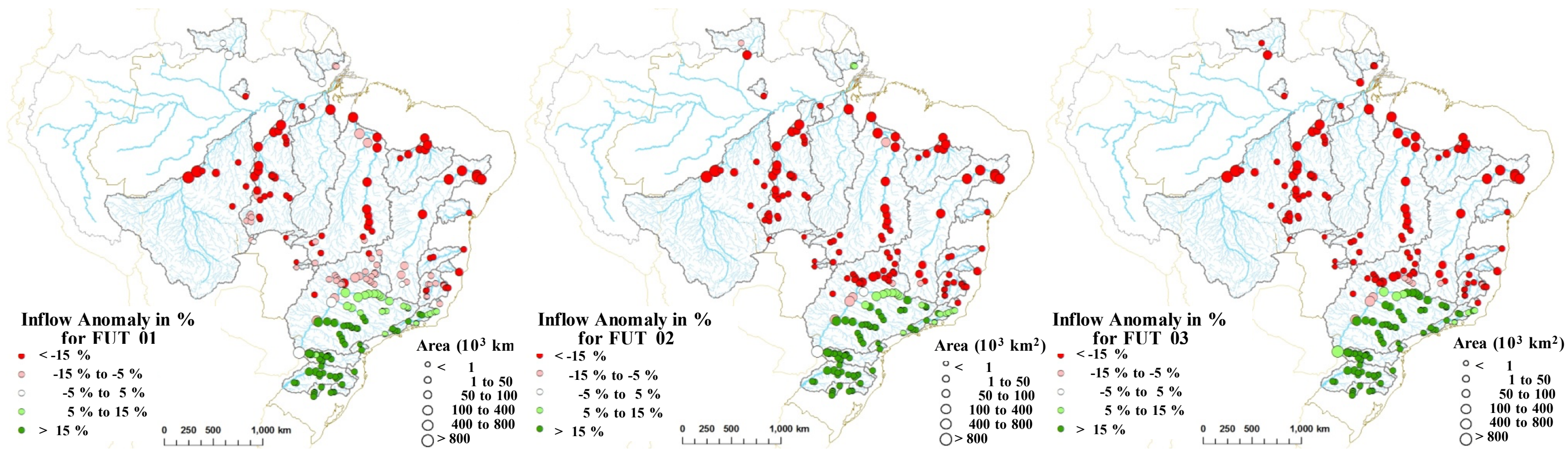




Simulation-Optimization Framework

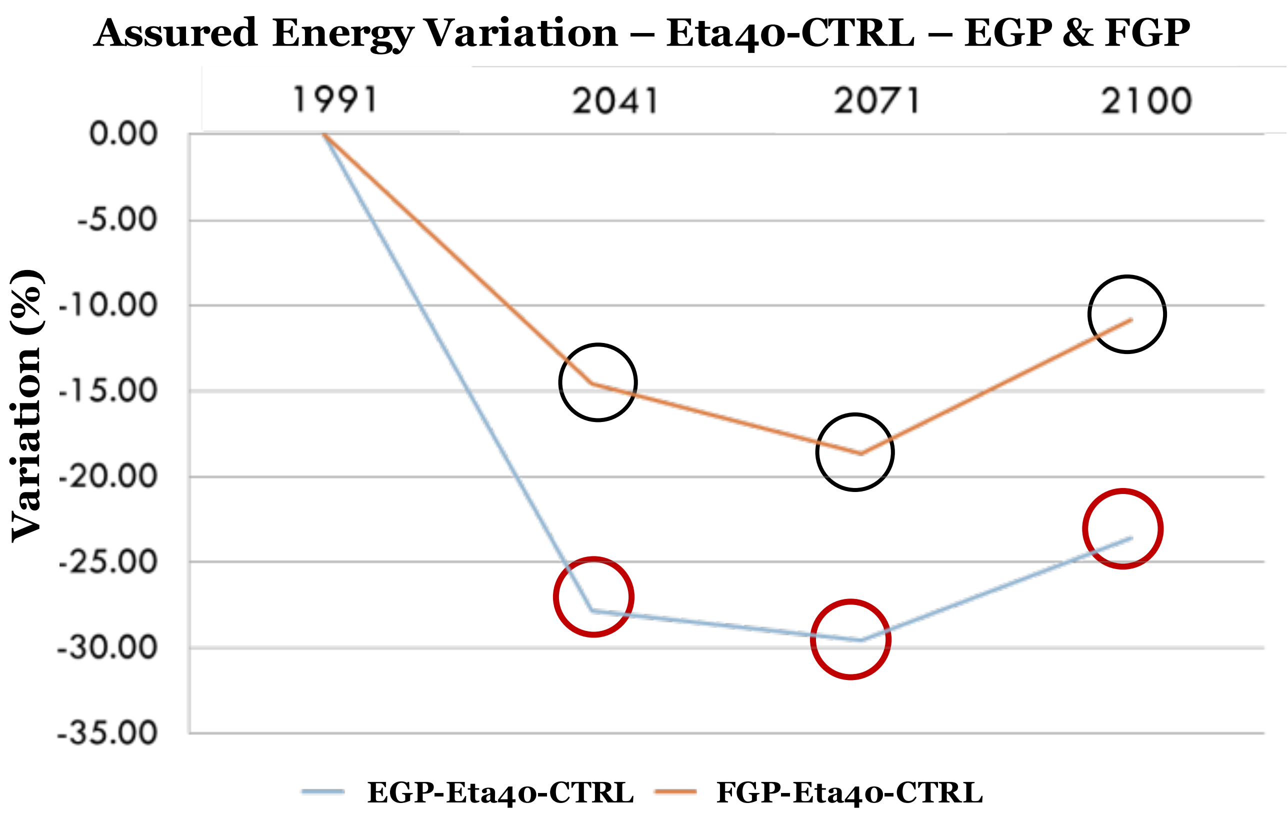
Framework used to obtain the hydro potential under different scenarios





Water inflows obtained from physical hydrological models that use climate information

Overall System Results

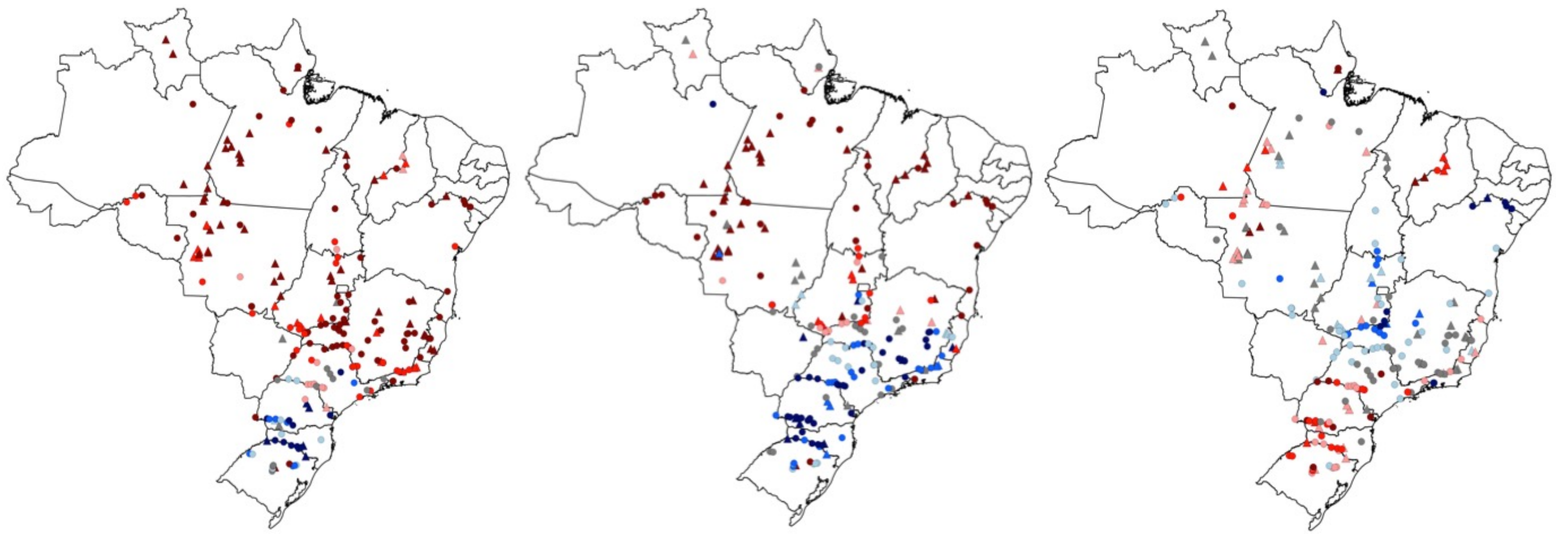


Larger reductions in the FGP due to the new hydro plants in the North – not producing as planned

AI03: Investment Opportunities

- We noticed that there are **potential problems** for the **total system assured energy** related to hydro
- However, there are places with positive trends of water inflows (historical and climate scenarios)
- One question that arises is: **do these new hydro projects make sense?**
- Another question is: should someone invest in projects for **hydro rehabilitation** (retrofit)?

Do These new Projects Make Sense?



Present - Fut_01   Fut_01 - Fut_02   Fut_01 - Fut_03

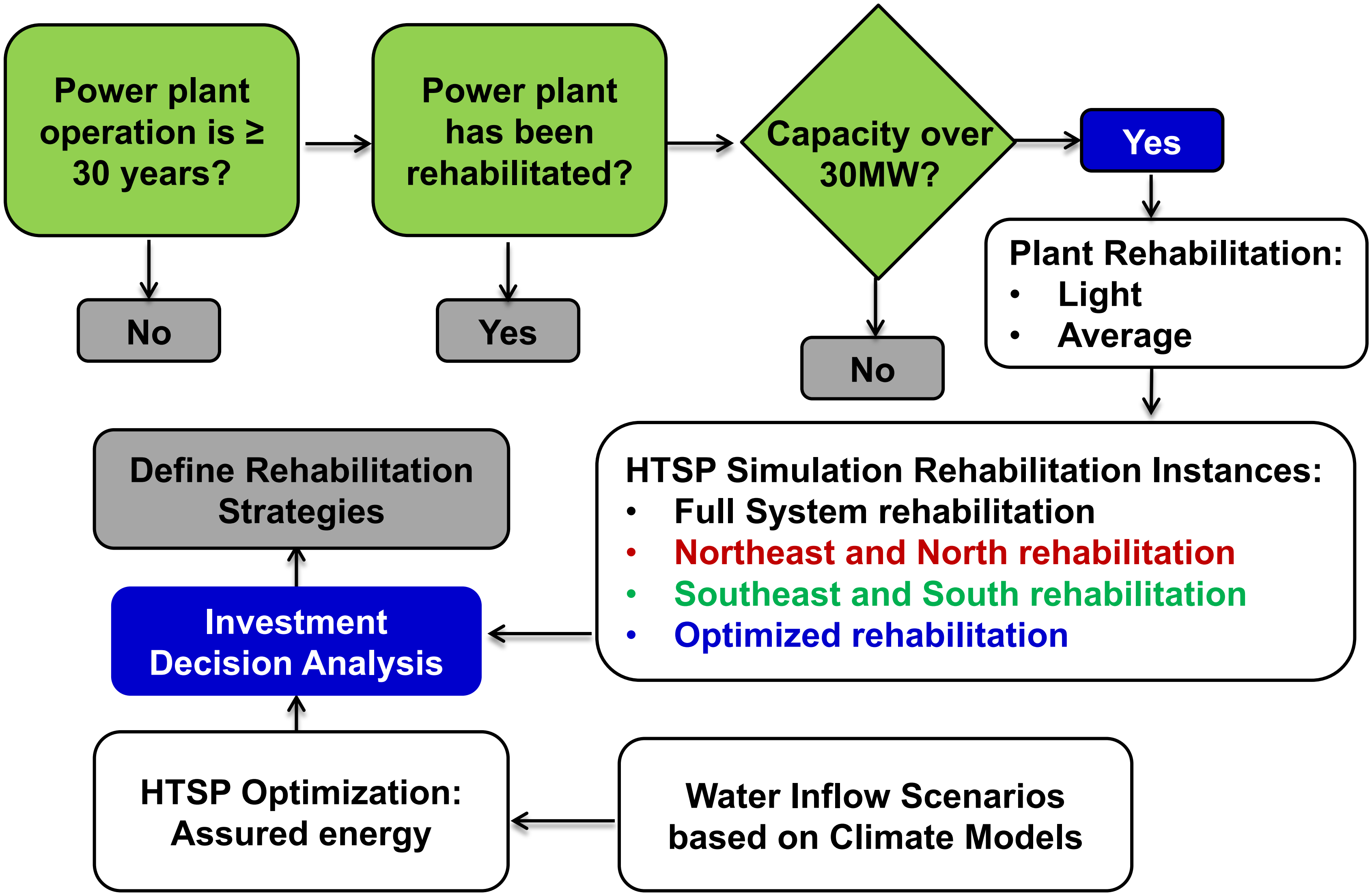
Hydro plant Exist - New	Percentage Changes in AE	Number of hydro plants		
		P - F1	F1-F2	F2-F3
● - ▲	<-25%	63-43	28-35	9-5
● - ▲	-25% to -15%	30-17	11-6	19-9
● - ▲	-15% to -5%	10-3	7-5	21-21
● - ▲	-5% to 5%	11-3	22-8	34-25
● - ▲	5% to 15%	8-1	18-4	36-8
● - ▲	15% to 25%	7-0	20-6	13-3
● - ▲	>25%	12-6	35-9	9-2

The answer we got at the individual level using different climate scenarios is that most of these new projects do not make sense!

The Other Question…

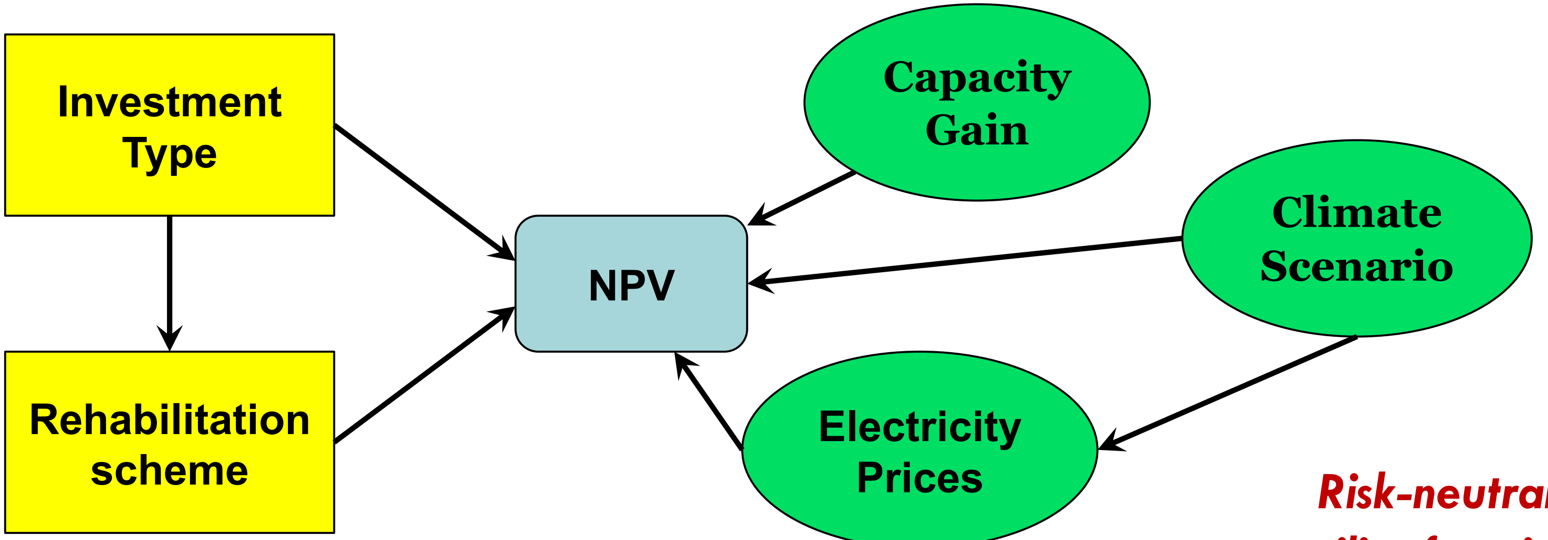
- Should someone invest in projects for **hydro rehabilitation** (retrofit)?
- Decide to invest or not in improvements in existent plants to increase their efficiency and capacity

Investment Decision Analysis Framework



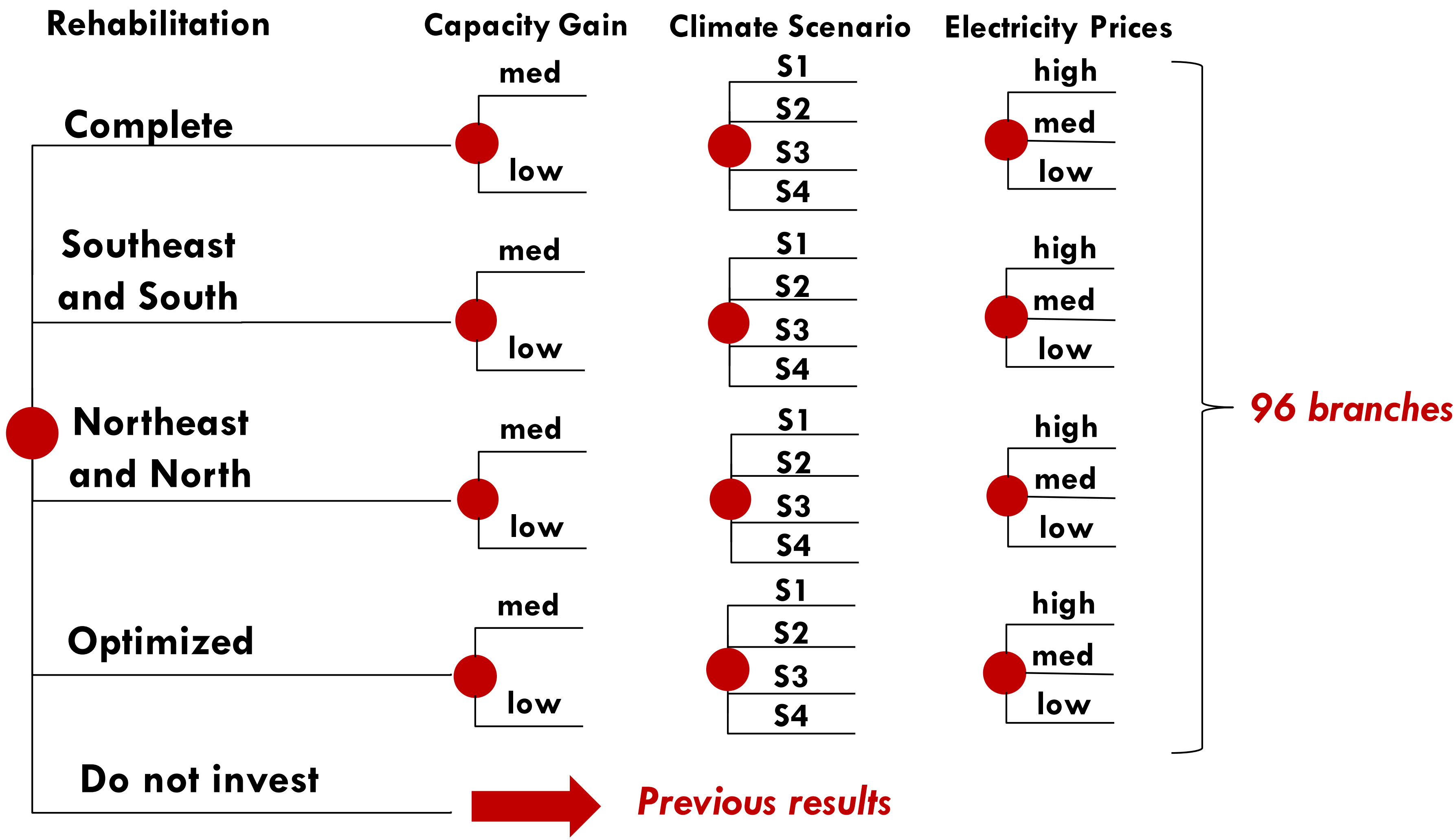
The Decision Analysis Problem

- There are a total of 50 candidate hydro plants - 28,083 [MW]
  - 33 SE (16941 MW), 9 S (5497 MW), 7 NE (5567 MW), 1 N (78 MW)
  - Optimized investment 24 plants from SE and S (9795 MW)
- We use the influence diagram to indicate existent dependencies among uncertainties and decisions



Risk-neutral utility function

Reduced Scenario Tree



Modeling Uncertainties

- Capacity gain (based on information of 16 executed projects)
  - Low (light rehab.): 8% capacity ↑ (prob = 56.3%)
  - Medium: 15% capacity ↑ (prob = 43.7%)

  *increase in capacity and probability based on historical information
- Climate scenario
  - Four scenarios (different CO_2 concentration)
  - Equal probability assigned to each scenario
- Electricity prices
  - Long-term energy auctions (H - 103, M - 85, L - 67 [$/MWh])

$$\{P_H\ |I_H\&\} = \frac{M_{P_H|I_H}}{M_{I_H}}$$

Two were considered as low water inflow scenarios

Inflow	Electricity Prices: High	Medium	Low
High	9.5	50.5	40
Medium	24.5	58.6	16.9
Low	26.5	52.9	20.6

Obtained Results

Rehabilitation	Investment [M US$]	NPV [Millions R$]
Complete	2,657	-996
Southeast and South	2,123	-870
Northeast and North	1,603	-283
Optimized	927	377
Do not invest	0	0

Calculated for 15 years using a 10% discount rate

The best alternative is given by the optimized investment

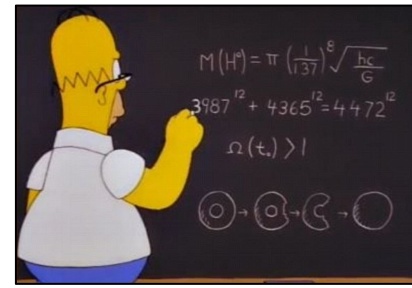
Final Comments

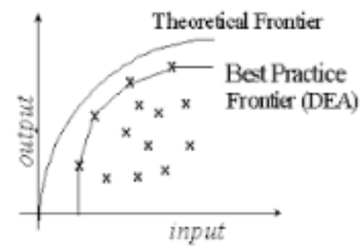
Final Comments

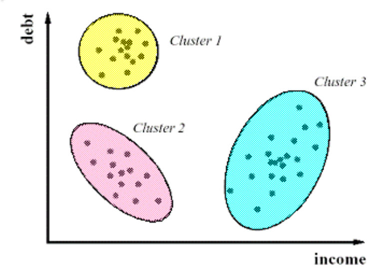
- We have presented the use of **applied analytics** to assess and evaluate the effects of **climate change in hydro power**
- We discussed a framework based on **stochastic programming and decision analysis** to provide useful information and support decision-making in problems related to investments in hydro power

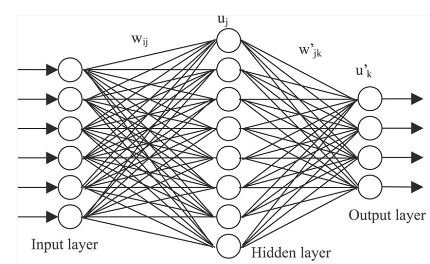
Other Research Topics

- Optimization Modeling and Analysis
- Benchmark Regulation
- Clustering Analysis
- Artificial Neural Networks
- Design of Experiments
- High-performance computing
- Portfolio Optimization









Thank You !

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