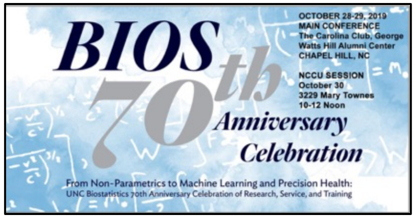


Data Analytics to Improve Wind and Hydro Coordination under the Threat of Climate Change

Dr. Anderson Rodrigo de Queiroz

NORTH CAROLINA CENTRAL UNIVERSITY
FOUNDED 1910

Durham, October 30th, 2019



Research Team

Anderson R. de Queiroz

NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910 | SCHOOL OF BUSINESS

José W. Marangon Lima

Luana M.M. Lima

Duke NICHOLAS SCHOOL OF THE ENVIRONMENT

Nayana Scherner

Overview

- Introduction
- Climate Change Effects in Energy Resources
- Wind and Hydro Time Series Construction
- Case Study
- Conclusions and Remarks

Introduction

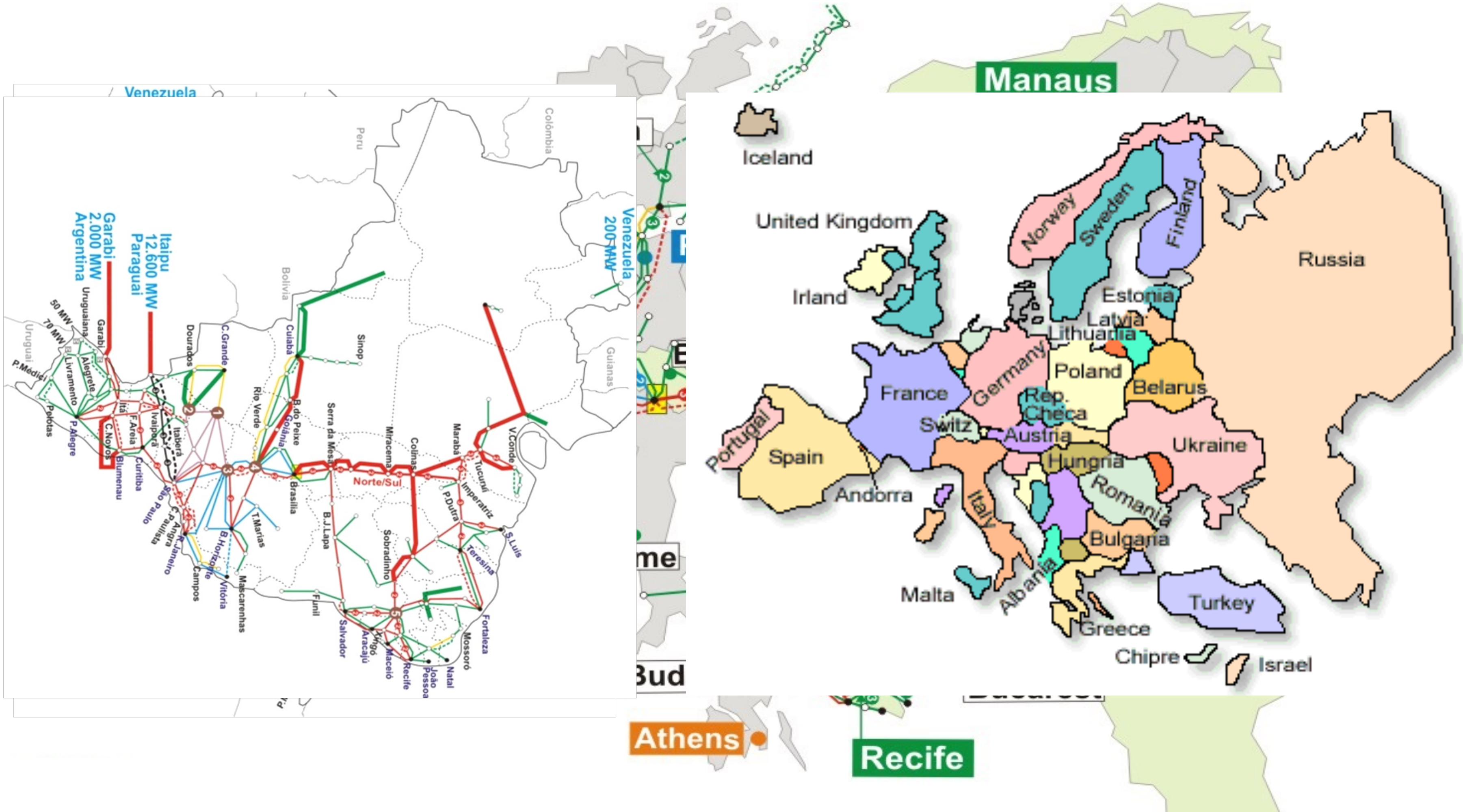
- **Renewable power** sources became a key aspect around the world by **disrupting old frontiers**
- These energy sources are linked to **sustainable development** that is one of the main goals of the modern society these days
- **The raise of renewable power installed** capacity demands new studies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

Introduction

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

São Paulo
(14.7 M)

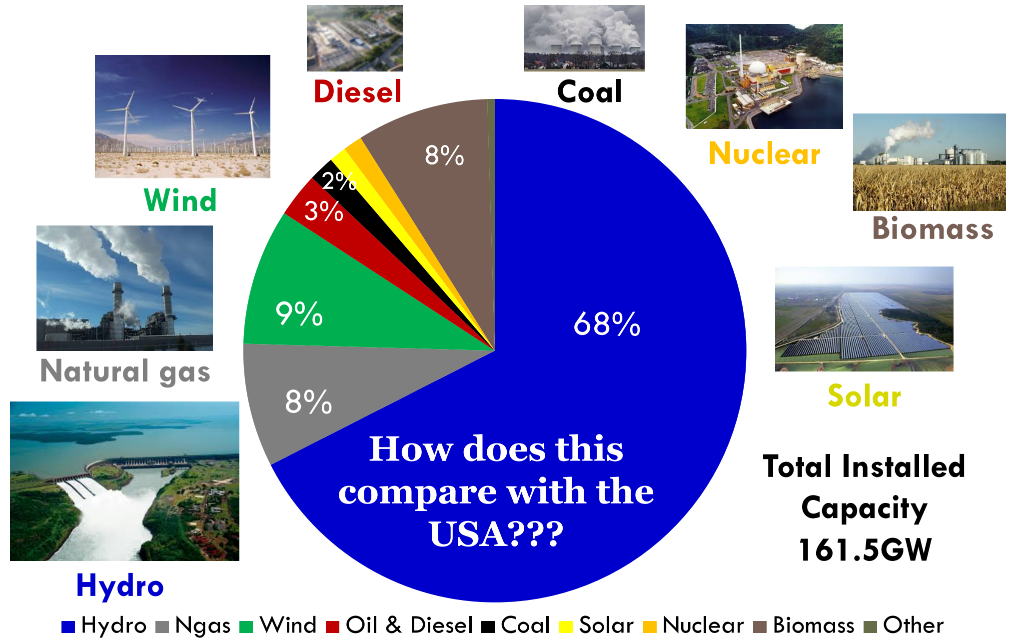
Dimensions of the Country



source: www.ons.org.br

Background

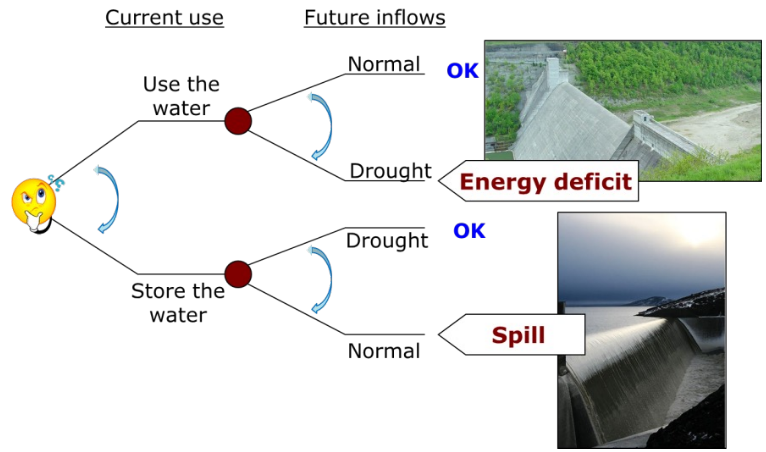
- Brazil presents a highly dominant renewable generation matrix (**mostly Hydro**)
- **Wind is a promising renewable** source in the country, reaching installed **capacity of 14.5 GW**



- The main problem with renewable power is its dependence on natural resources (**may not be available when necessary**)
- Often represented as uncertainty sources for decision-making models in power systems

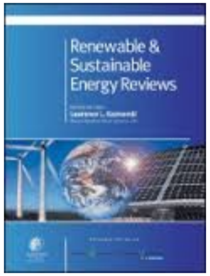
Stochastic Hydro-thermal Coordination

- 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



HTCP Model Formulation for Stage-t

Present Cost / **Expected Future Cost**

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

Water Balance

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

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

$$\underline{x_i^t} \leq x_i^t \leq \overline{x}_i^t \quad \forall i \in I$$

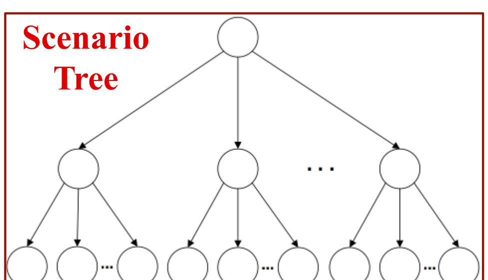
$$0 \leq GH_i^t \leq \overline{GH_i^t} \quad \forall i \in I$$

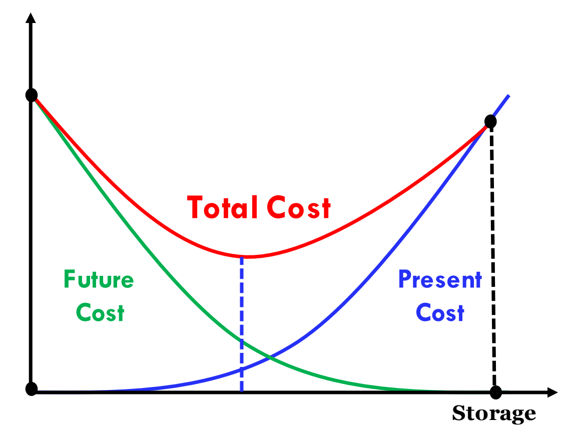
$$0 \leq S_i^t \quad \forall i \in I$$

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

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

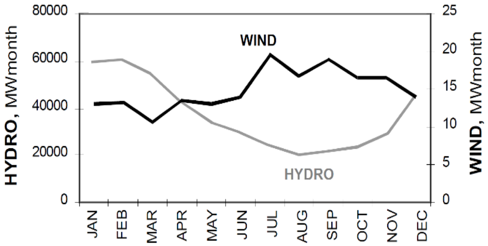
$$0 \leq F_{r\,r'}^t \leq \overline{F_{r\,r'}^t} \quad \forall (r, r') \in R$$





Wind – Hydro Complementary

- Previous works show **complementary behavior** between **wind** and **hydro power**
- Studies generally investigate the **potential correlation in historical series** of wind speed and water inflows
- e.g. regions of Canada (Denault et al., 2009) Mexico (Jamarillo et al., 2004)
- Some of the analysis were conducted using the Brazilian system as (Witzler, 2015; Amarante et al., 2011; Silva et al., 2014). Overall:
  - **Northeast** region shows **negative correlation**
  - **South** region shows **positive correlation**



HTCP Model with Wind Penetration

Present Cost — **Future Cost Function**

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

Water Balance

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

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

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

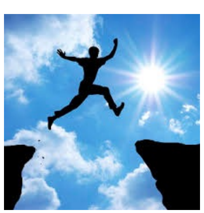
Demand Satisfaction

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

Maximum wind power generation

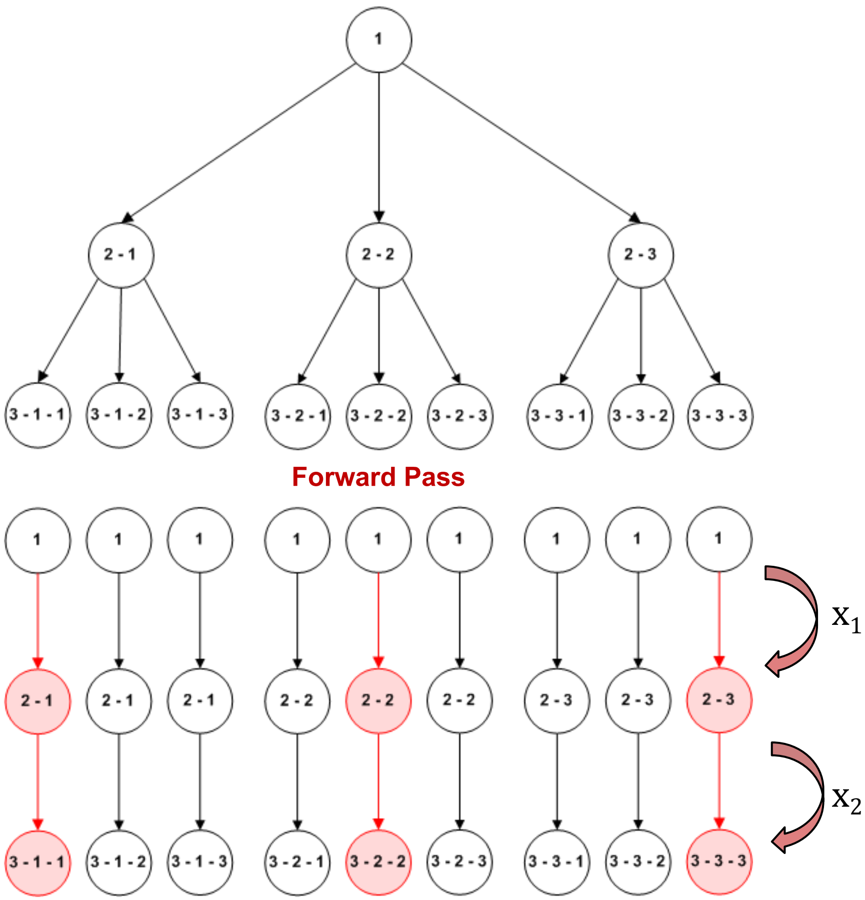
Simple bounds

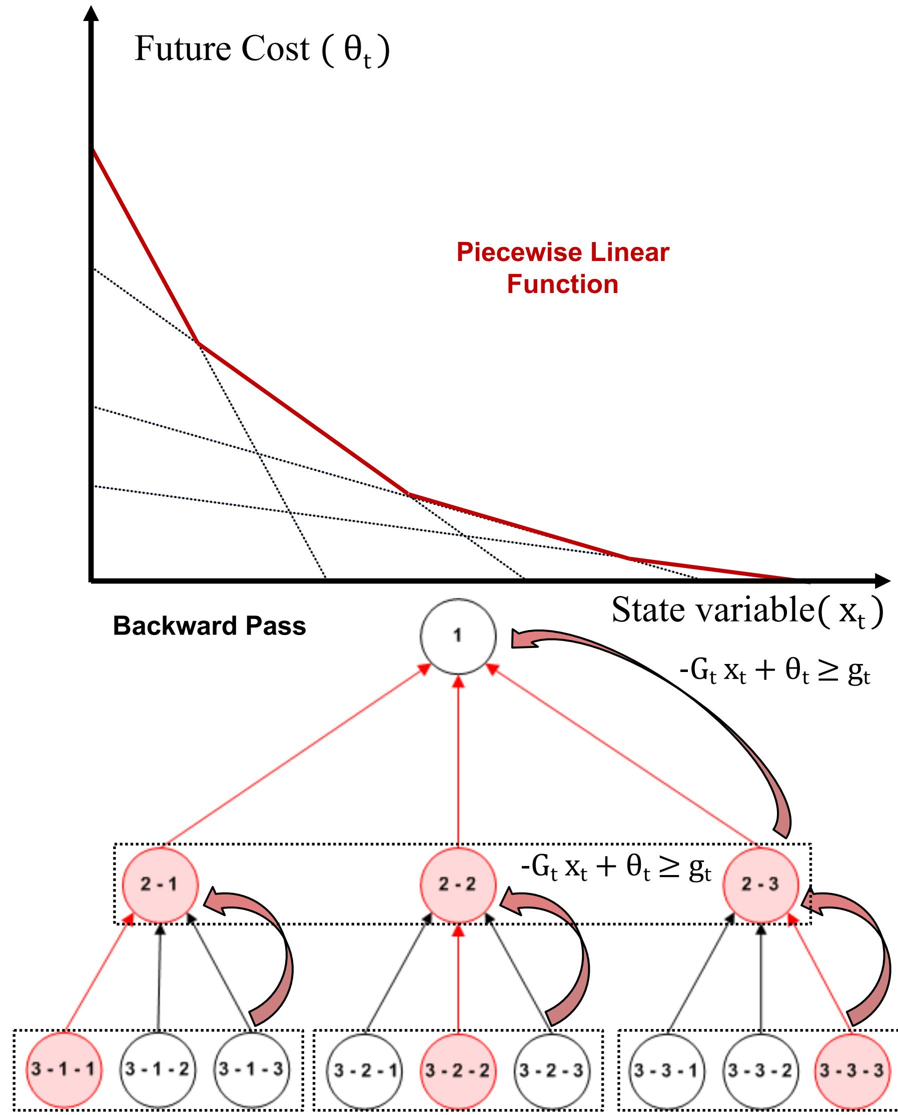
Silva, S.R., de Queiroz, A.R., Lima, L.M.M., Lima, J.W.M., (2014) Effects of Wind Penetration in the Scheduling of a Hydro-Dominant Power System, IEEE PES General Meeting



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

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

Climate Change Effects

CLIMATE HOME

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Home Politics World Energy Finance Cities Technology Science Opinion

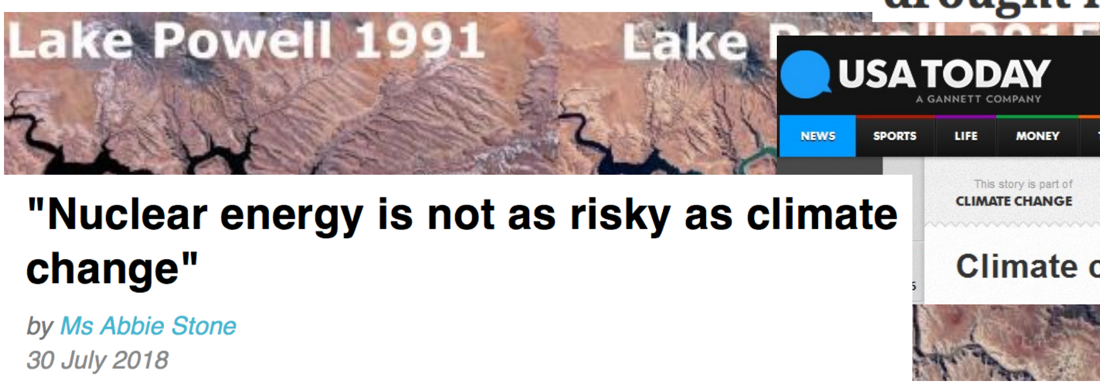
2C Adaptation Antarctic Arctic Corals Forests Glaciers Research Nature Water

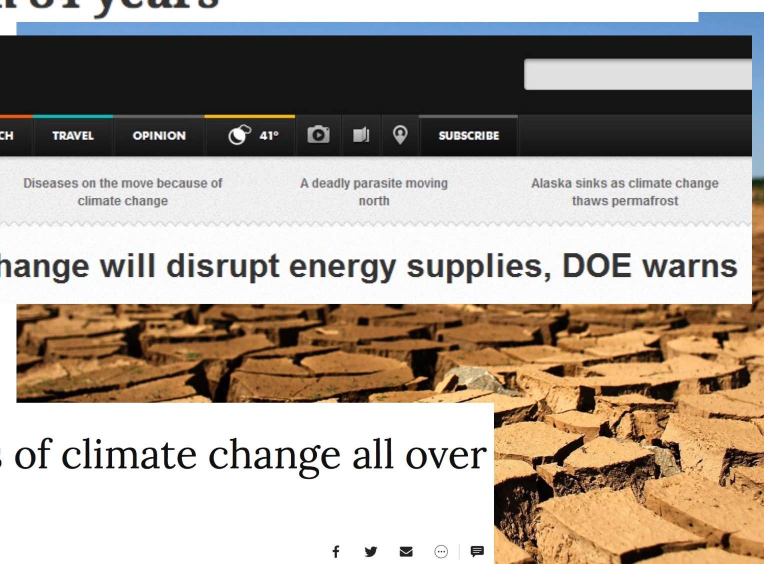
Is climate change driving Brazil's drought chaos?

NASA, Global Climate Change

Paul N

Brazil faces water rationing amid worst drought in 84 years





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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

Climate change will disrupt energy supplies, DOE warns

"Nuclear energy is not as risky as climate change"

by Ms Abbie Stone
30 July 2018

US & WORLD // SCIENCE

Scientists see fingerprints of climate change all over California's wildfires

Kurtis Alexander | Aug. 3, 2018 | Updated: Aug. 3, 2018 1:05 p.m.

Believers vs

go.ncsu.edu/denial

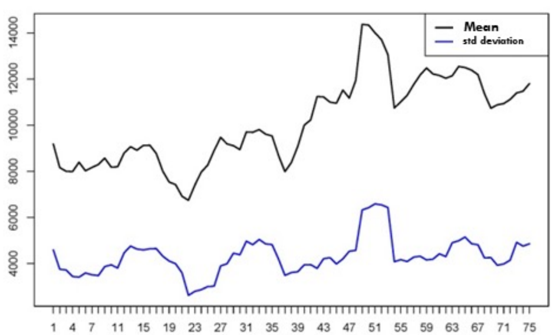
Climate Change – Basics

- First of all what is climate change?

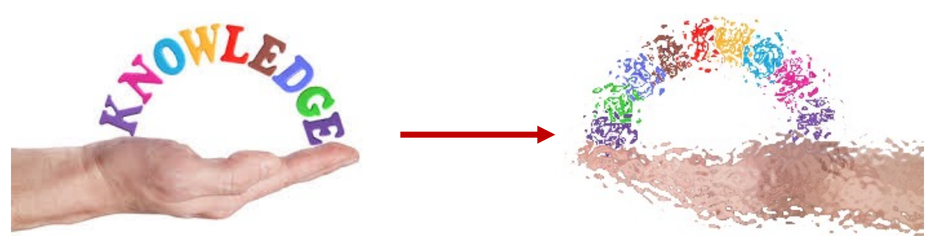
"Climate change is a ***change in the statistical distribution of weather patterns*** *when that lasts for an* ***extended period of time****"*

(Wikipedia, 2016)

"Scientific evidence for warming of the climate system is unequivocal"



4th IPCC report ← (NASA, 2016)



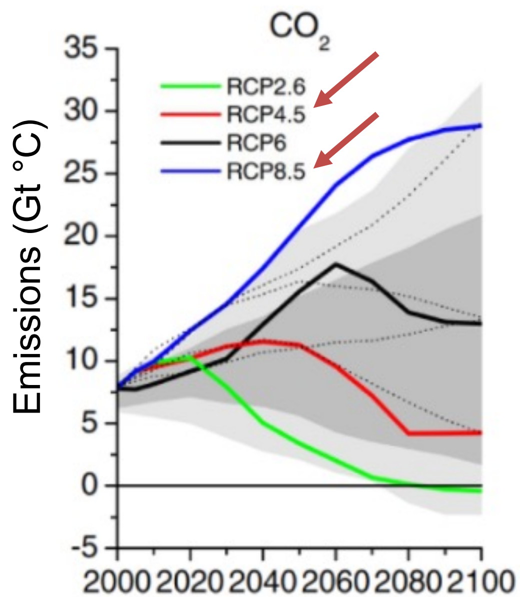
Climate change may modify our knowledge about the system

Global Climate Models

- **Global Climate Models**(GCMs) are the main tools that represent the global climate variations. We will be looking at information of two GCMs:
  - **HadGEMs-ES**
  - **MIROC5**
- **Regional Climate Models** (RCMs) are often used to improve the resolution
  - **ETA HadGEMs-ES**
  - **ETA MIROC5**
- Two periods are defined for the analysis
  - **Historical: 1961 – 1990**
  - **Future: 2011 – 2100**

GCM's resolution 100-200 km

RCM's resolution 20-40 km



*from 5th IPCC report

Study Goals

- Verify if the **intensity of wind speed and precipitation remains similar and if the complementary** behavior among sources may be affected by future climate
- **Generate synthetic series** for wind speed and water inflows **using future climate information**



METHODOLOGY

Future Wind Time Series from GCMs

- We attempt to build **future wind time series** from outputs of **GCMs - RCMs runs**, and consider:
  - Daily wind speed averages
  - **Information gathered at 10 m height**
- However it is necessary to **transform** that information at the **wind turbine heights (~100m)**
- We employ the **method of the logarithm** to do that

$$v = \frac{v^*}{0.4}\left(ln\left(\frac{h}{Z_0}\right) - \Psi\right)$$

- v: Wind speed at 100m height
- v^*: Friction speed computed at 10m height
- h: height in [m] of the turbine
- Ψ: Warm flux profile in the region (affects speed)
- Z_0: Soil roughness of the region (~0.3m)

(Lange et al., 2014)

Future Wind Time Series from GCMs *(cont')*

- **Determine stability characteristics of the regions**
- Warm flux is determined for 3 atmospheric conditions

$$\Psi_U = \left(1 - 16\frac{\mathrm{h}}{\mathrm{L}}\right)^{1/4}$$

$$\Psi_S = -4.7\frac{\mathrm{h}}{\mathrm{L}}$$

$$\Psi_N = 0$$

Data from Vestas is used to determine the stability conditions for each month based on the past data using **Richardson criteria**

$$RI = \frac{g}{\left(\frac{T_1 + T_2}{2} + K\right)} \times \frac{(T_2 - T_1)\times(h_2 - h_1)}{(v_2 - v_1)^2}$$

RI< -0.03 → Unstable (U)

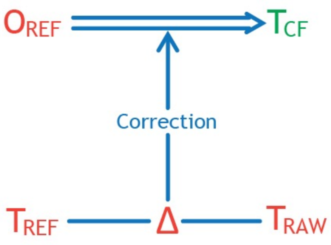
RI > 0.01→ Stable (S)

-0.03 ≤ RI ≤ 0.01 → Neutral (N)

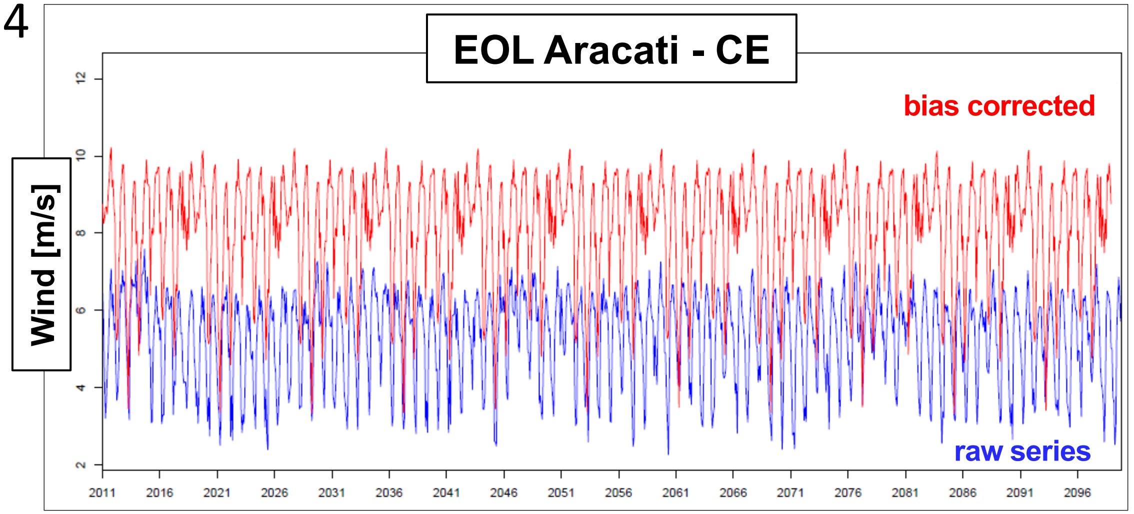
$$v_{dm} = v_d^S f_m^S + v_d^U f_m^U + v_d^N f_m^N$$

(Lange et al., 2014)

Future Wind Time Series from GCMs *(cont')*



- **Perform bias correction (Teutschbein and Seibert, 2012)**
- We make use of the **delta change method** to determine **anomalies** in the values estimated from the CGMs **between the historical** and **future** periods
- These **anomalies are then applied to the real historical data**
  - Vortex model 1983-2014
- The future time series is then reconstructed



Probability Distributions

- Several probability distributions (PD) were tested
  - Normal or Gaussian
  - Weibull
  - Exponential
  - Rayleigh
  - Weibull → **Best to fit the data**

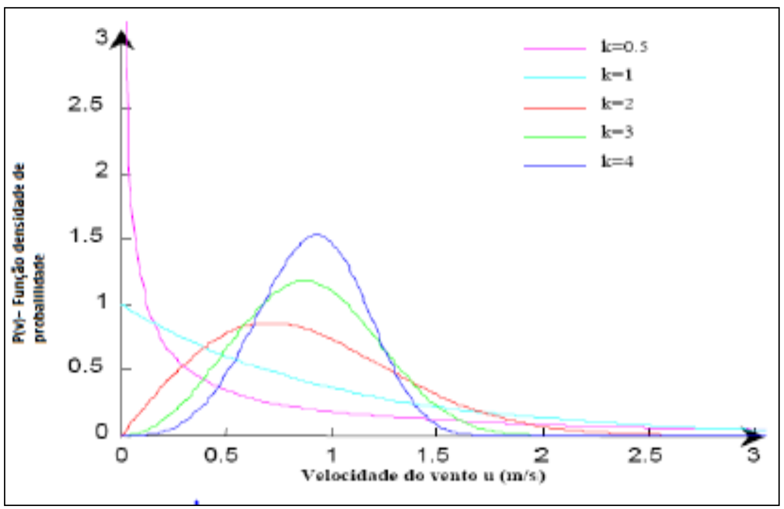
Cumulative density functions

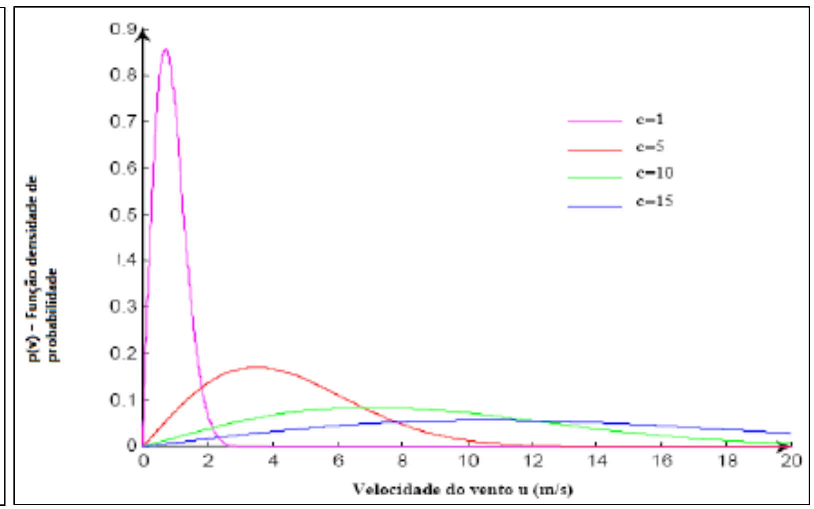
$$p(v_a \le v \le v_b) = \sum_{i=a}^{b} p(v_i)$$

$$k = \left(\frac{\sigma_v}{\bar{v}}\right)^{-1{,}086}$$

$$c = \bar{v}\left(0{,}568 + \frac{0{,}433}{k}\right)^{\frac{-1}{k}}$$

$$p(v) = \left(\frac{k}{c}\right)\left(\frac{v}{c}\right)^{k-1} exp\left[-\left(\frac{v}{c}\right)^{k}\right]$$



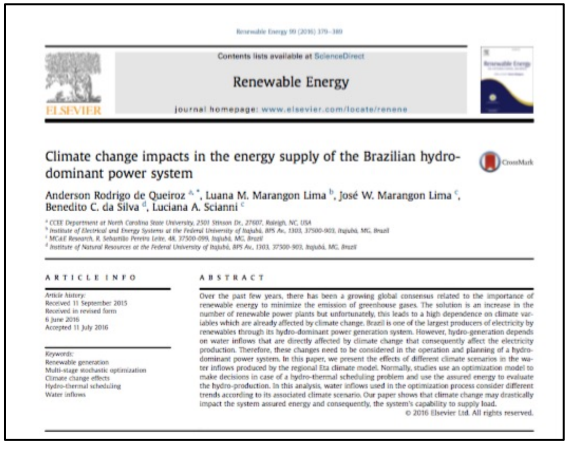


Future Water Inflow Series from GCMs

- We use the **historical inflow time series** from the Brazilian Independent System Operator (ONS)
- We build future water inflow time series using the **large hydro basins rainfall-runoff model (MGB)** (Collischonn et al., 2007)
- MGB input information:
  - Climatological values
  - Hydrological data
  - GIS information

More details about the use of MGB to generate future water inflows can be found at:

*De QUEIROZ, A.R., LIMA, L.M.M., LIMA, J.W.M., SILVA, B.C., SCIANNI, L.A., **Climate Change Impacts in the Energy Supply of the Brazilian Hydro-dominant Power System, Renewable Energy, 99: 379-389, 2016***



Renewable Energy 99 (2016) 379–389

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Renewable Energy

journal homepage: www.elsevier.com/locate/renene

Climate change impacts in the energy supply of the Brazilian hydro-dominant power system

Anderson Rodrigo de Queiroz [a,*], Luana M. Marangon Lima [b], José W. Marangon Lima [c], Benedito C. da Silva [d], Luciana A. Scianni [c]

[a] CCEE Department at North Carolina State University, 2501 Stinson Dr., 27607, Raleigh, NC, USA
[b] Institute of Electrical and Energy Systems at the Federal University of Itajubá, BPS Av., 1303, 37500-903, Itajubá, MG, Brazil
[c] MC&E Research, R. Sebastião Pereira Leite, 48, 37500-099, Itajubá, MG, Brazil
[d] Institute of Natural Resources at the Federal University of Itajubá, BPS Av., 1303, 37500-903, Itajubá, MG, Brazil

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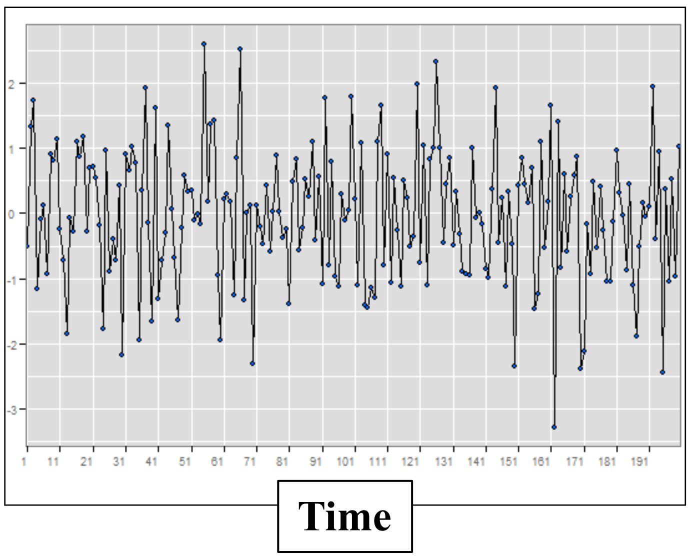
ABSTRACT

Over the past few years, there has been a growing global consensus related to the importance of renewable energy to minimize the emission of greenhouse gases. The solution is an increase in the number of renewable power plants but unfortunately, this leads to a high dependence on climate variables which are already affected by climate change. Brazil is one of the largest producers of electricity by renewables through its hydro-dominant power generation system. However, hydro-generation depends on water inflows that are directly affected by climate change that consequently affect the electricity production. Therefore, these changes need to be considered in the operation and planning of a hydro-dominant power system. In this paper, we present the effects of different climate scenarios in the water inflows produced by the regional Eta climate model. Normally, studies use an optimization model to make decisions in case of a hydro-thermal scheduling problem and use the assured energy to evaluate the hydro-production. In this analysis, water inflows used in the optimization process consider different trends according to its associated climate scenario. Our paper shows that climate change may drastically impact the system assured energy and consequently, the system's capability to supply load.

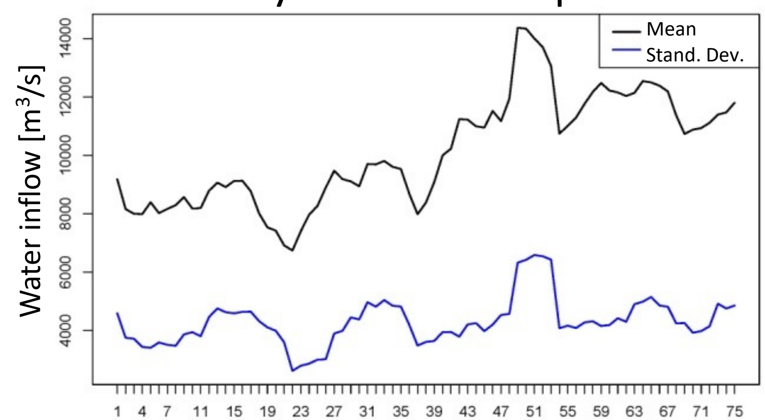
Is the Time Series Stationary?

- Evaluate potential trends positive (or negative) in the data
- We run different tests to obtain our results



Run tests to check for potential trends in the data

Hydro Plant: Itaipu



Milly et al., Stationarity Is Dead: Whither Water Management?, Science, 319(5863):573-574, 2008

CASE STUDY

Region in Analysis

Wind and Hydro Projects in Analysis

Wind

CIDADE	ESTADO
Amontada	Northeast / Ceará
Aracati	Northeast / Ceará
Paracuru	Northeast / Ceará
Caetité	Northeast / Bahia
Morro do Chapéu	Northeast / Bahia
Pedra do Reino	Northeast / Bahia
Currais Novos	Northeast / RG do Norte
João Câmara	Northeast / RG do Norte
Macau	Northeast / RG do Norte
Coxilha Negra	South / RG do Sul
Estrada Senandes	South / RG do Sul
Tramandaí	South / RG do Sul

Projects winners of the long-term energy auctions (LER, LEN, LFA)

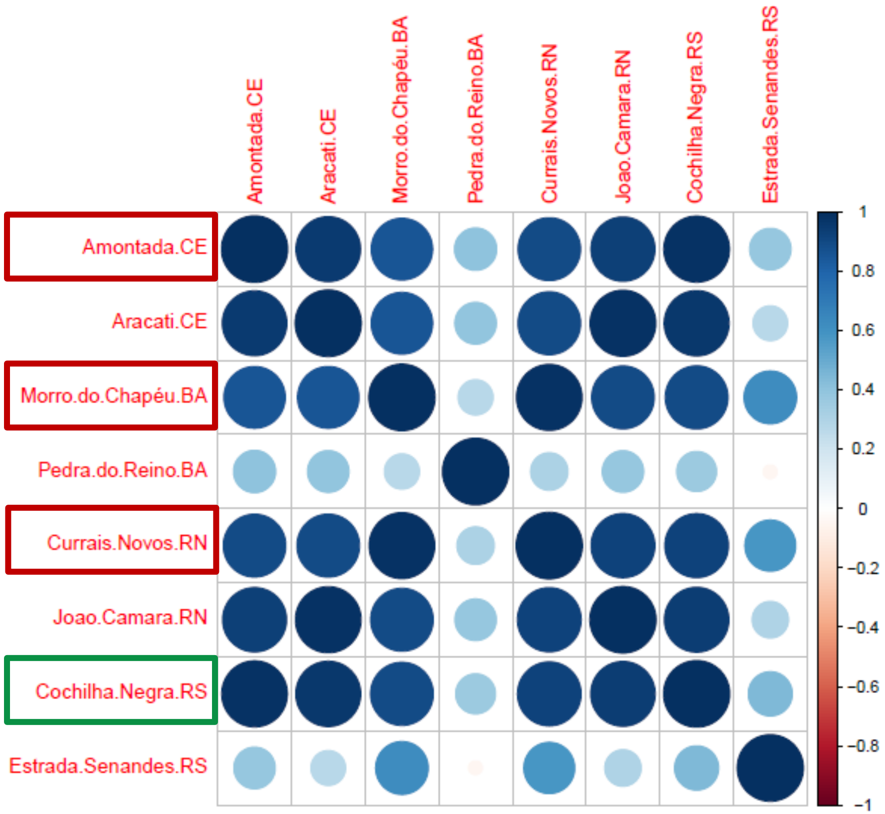
Hydro

CIDADE	ESTADO
UHE Sobradinho	Northeast / S. Francisco basin
UHE Complexo Paulo Afonso	Northeast / S. Francisco basin
UHE Dona Francisca	South / Jacui basin
UHE Castro Alves	South Taq.-Antas basin

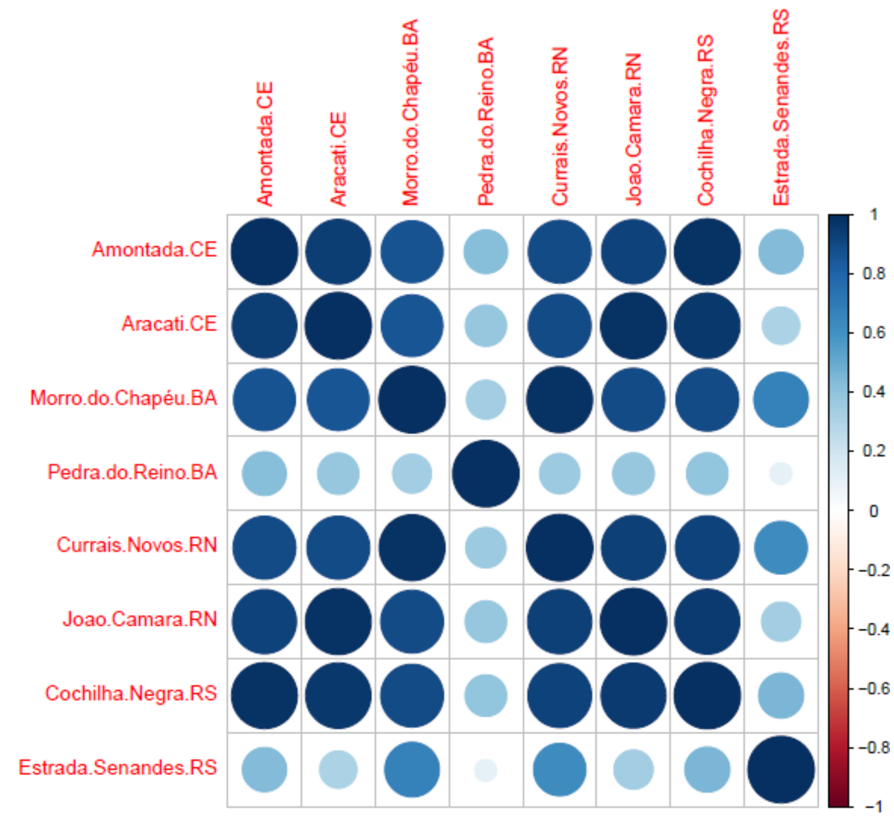
Existent hydro power plants

Witzler (2015) and EPE (2013)

Correlation Analysis – Wind Farms



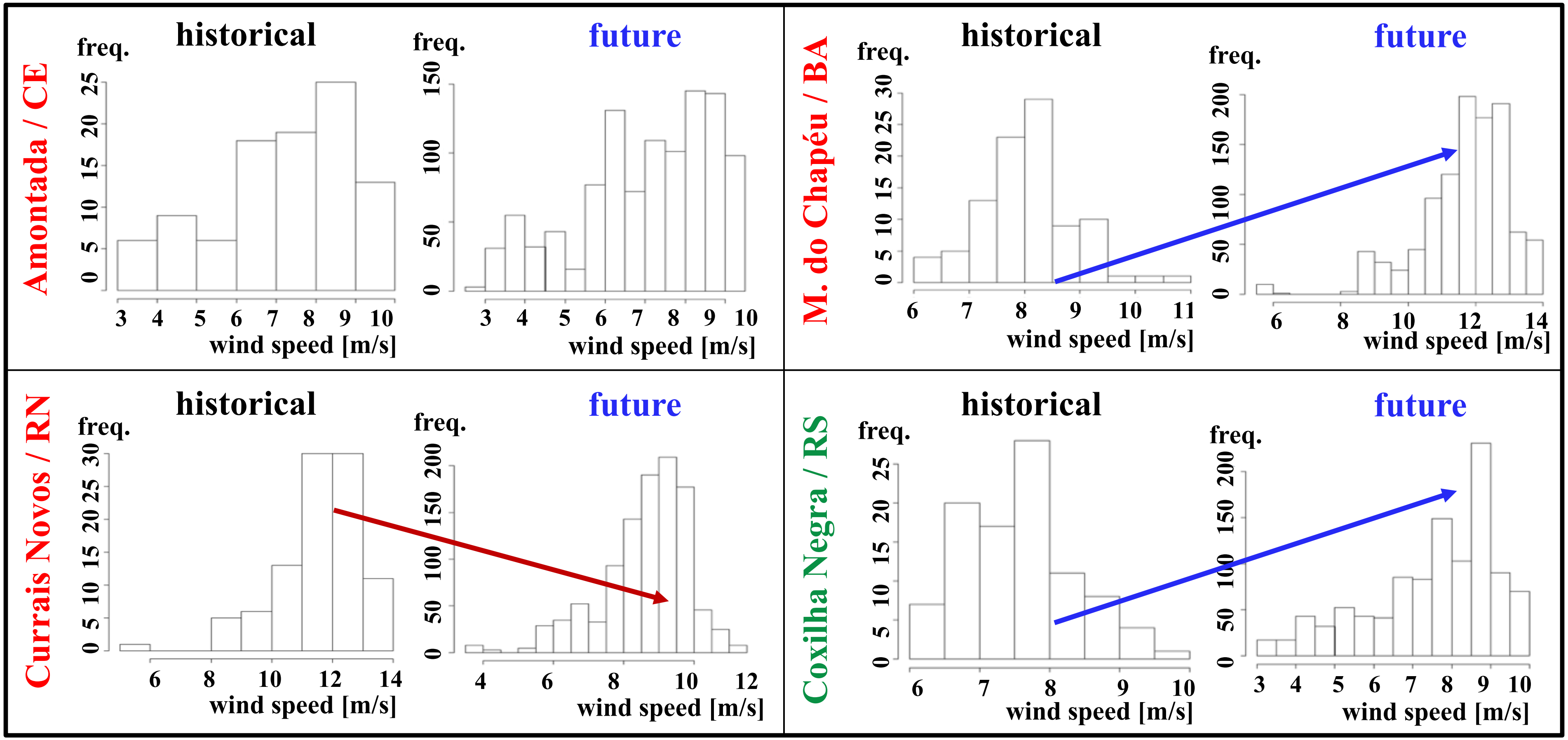
ETA-HadGEMs-ES 8.5



ETA-MIROC5 8.5

*Due to similarities we restrict the analysis

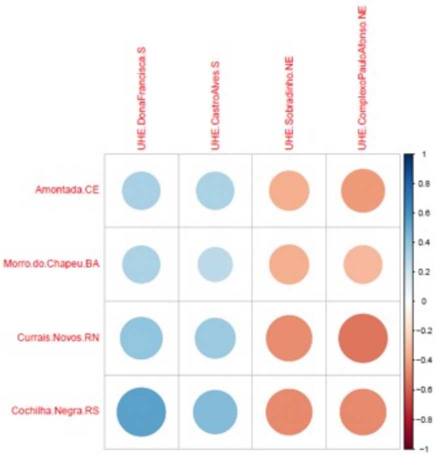
Wind Speed Histograms



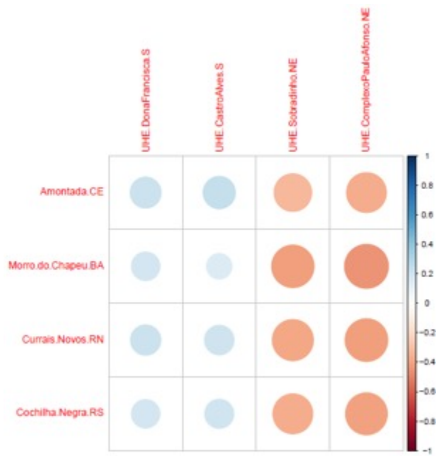
Small reduction in wind speed

Increase in speed and change of distributions shapes

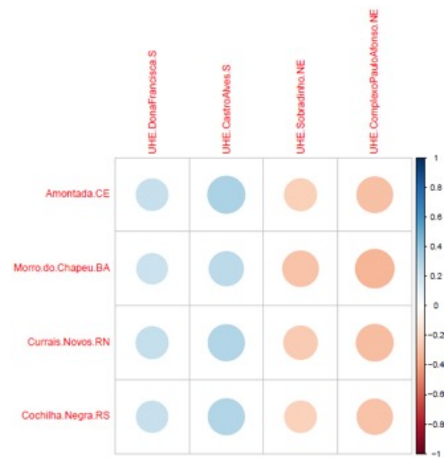
Long-term Complementary Behavior



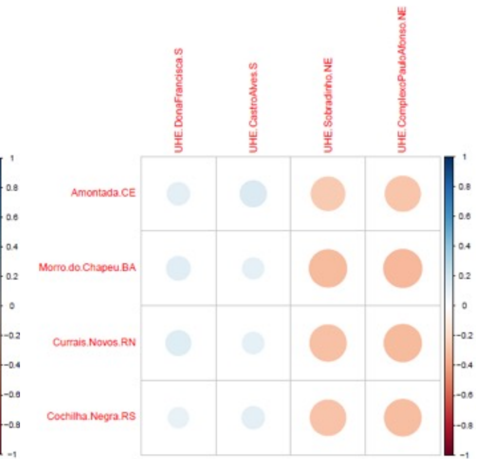
historical



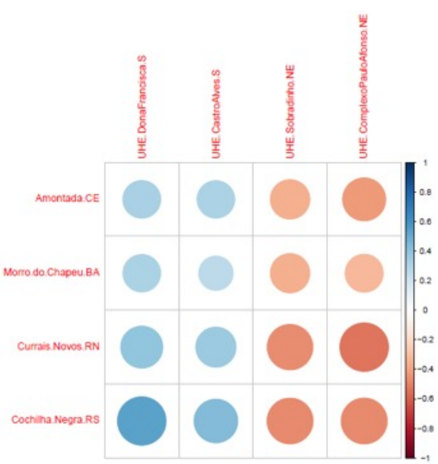
HadGEMs ES8.5 Fut 1



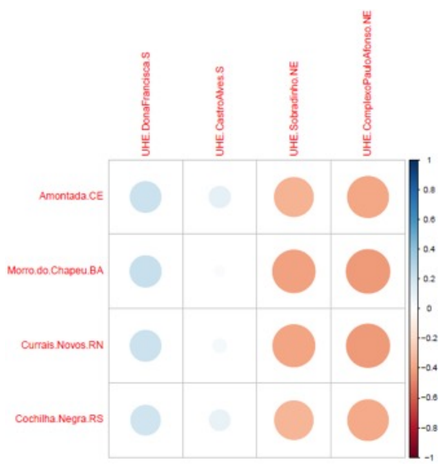
HadGEMs ES8.5 Fut 2



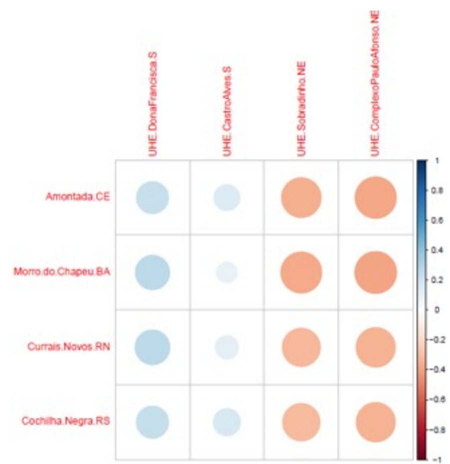
HadGEMs ES8.5 Fut 3



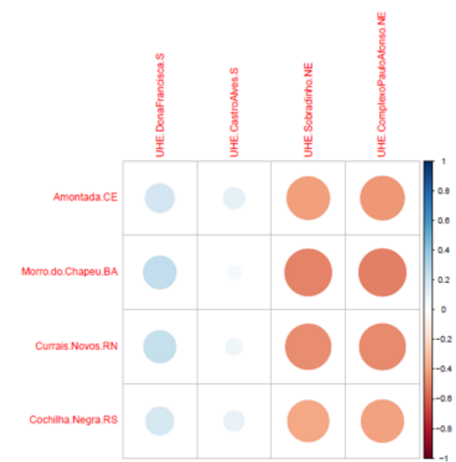
historical



Eta – Miroc 8.5 Fut 1



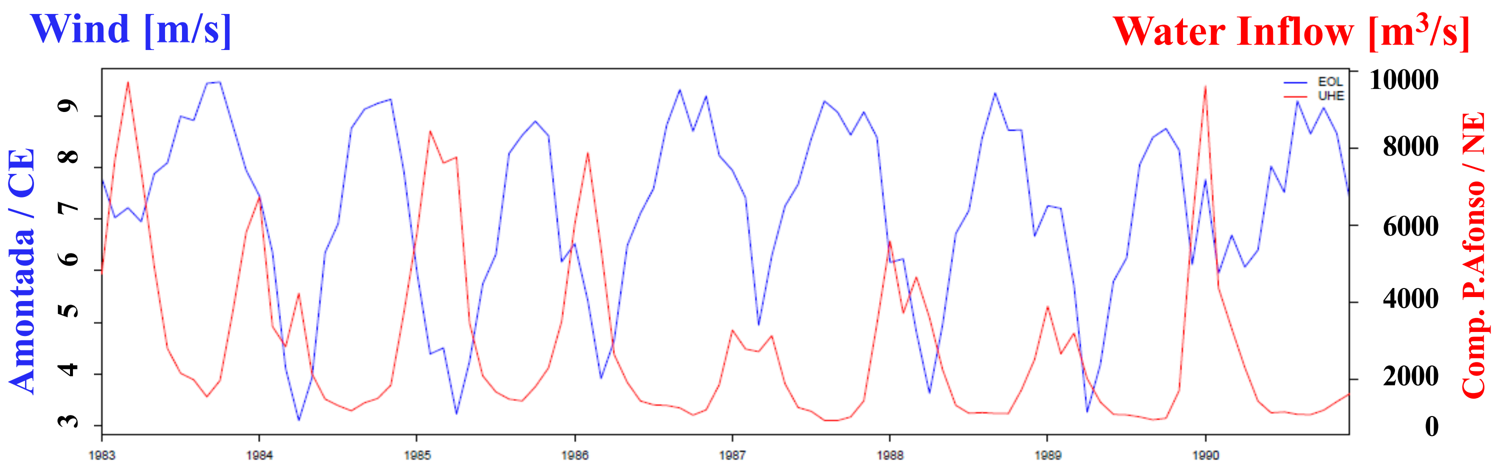
Eta – Miroc 8.5 Fut 2



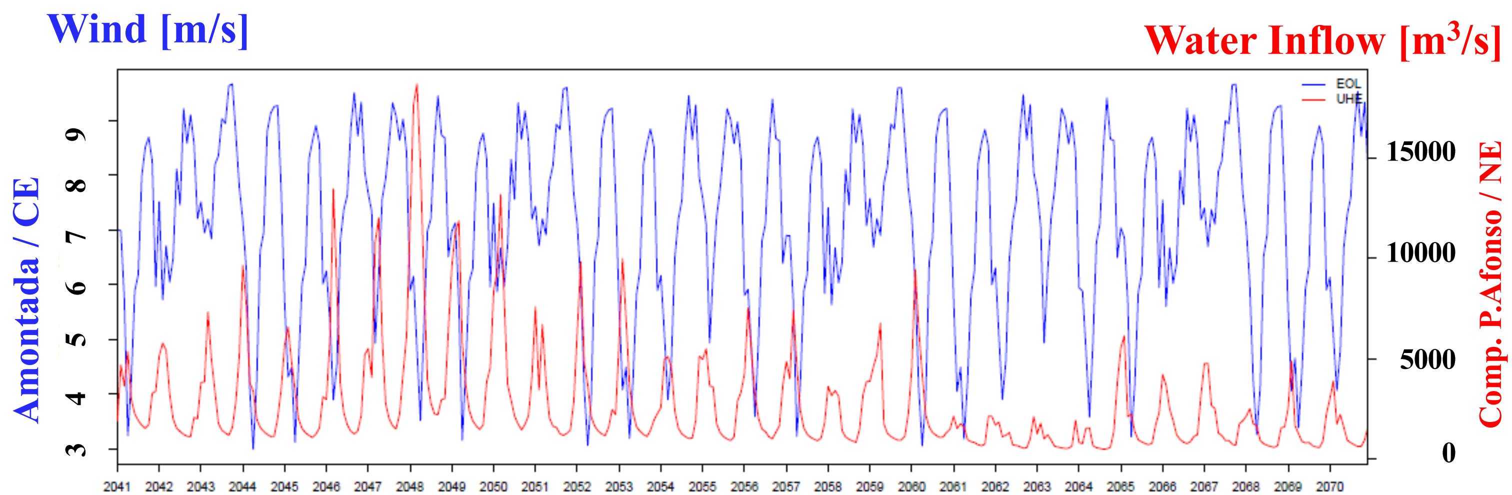
Eta – Miroc 8.5 Fut 3

Future Wind and Water Inflow Series

historical



future



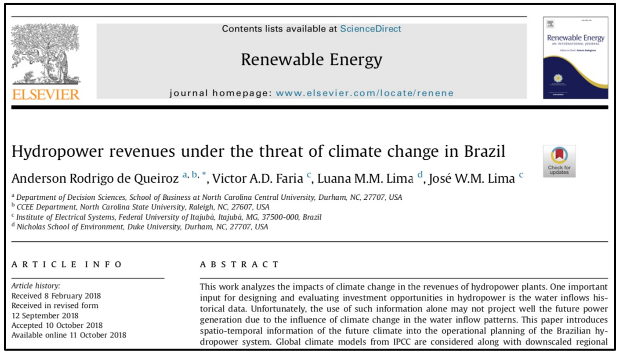
ETA-HadGEMs-ES 8.5

Conclusions & Remarks

- The impacts of the wind in the context of the power generation scheduling problem is relevant when installed capacity scales up → **better models**
- We presented a methodology to create wind time series based on GCMs – RCMs runs
- Applied analytical methods and observed that:
  - Complementary effects between hydro and wind power may be slightly affected in the future (regions in analysis)
  - It was observed negative correlation in the NE of Brazil (lesser than for the historical period)
  - Reduction of the positive correlation in the S

There is a strong need to consider changes in climate when performing long-term planning / operational studies within the decision-making framework

*de Queiroz, A. R., Faria, V. A., Lima, L. M., & Lima, J. W. (2019). **Hydropower revenues under the threat of climate change in Brazil. Renewable Energy, 133, 873-882***



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Hydropower revenues under the threat of climate change in Brazil

Anderson Rodrigo de Queiroz [a, b, *], Victor A.D. Faria [c], Luana M.M. Lima [d], José W.M. Lima [c]

[a] Department of Decision Sciences, School of Business at North Carolina Central University, Durham, NC, 27707, USA
[b] CCEE Department, North Carolina State University, Raleigh, NC, 27607, USA
[c] Institute of Electrical Systems, Federal University of Itajubá, Itajubá, MG, 37500-000, Brazil
[d] Nicholas School of Environment, Duke University, Durham, NC, 27707, USA

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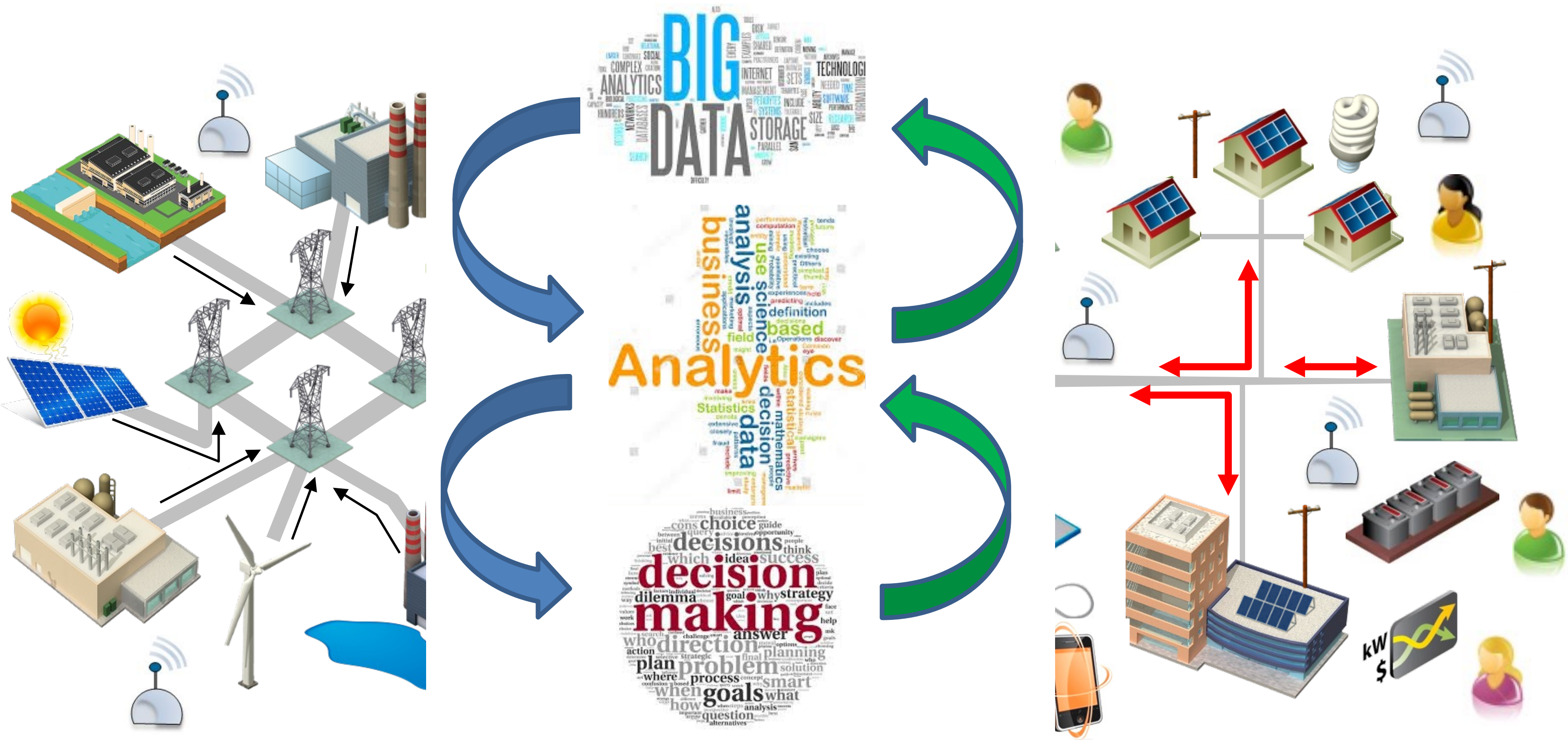
ABSTRACT

This work analyzes the impacts of climate change in the revenues of hydropower plants. One important input for designing and evaluating investment opportunities in hydropower is the water inflows historical data. Unfortunately, the use of such information alone may not project well the future power generation due to the influence of climate change in the water inflow patterns. This paper introduces spatio-temporal information of the future climate into the operational planning of the Brazilian hydropower system. Global climate models from IPCC are considered along with downscaled regional

Final Comments - Integrated Vision



Present/Future Systems have to be highly Flexible, Resilient and Connected where Resources are Optimized

Thank You !

adequeiroz@nccu.edu
ar_queiroz@yahoo.com.br
https://arqueiroz.wordpress.ncsu.edu

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