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

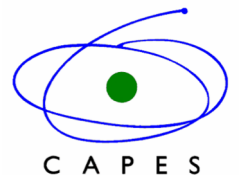
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Panel Session: Big Data Analytics for Flexible Electricity
Networks, Markets and Prosumers



Research Team



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Overview

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

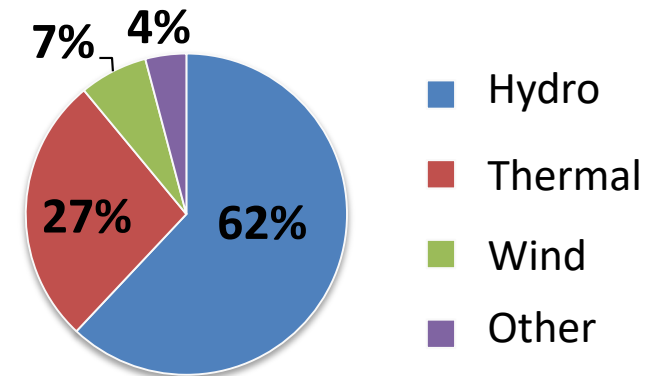
Introduction

- **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



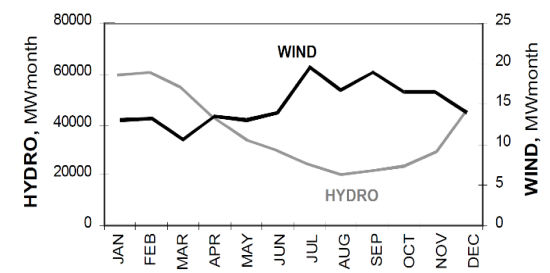
Background

- Brazil presents a highly dominant renewable generation matrix (**mostly Hydro**)
- **Wind is a promising renewable** source in the country, reaching installed **capacity of 11.9 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



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**



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**

Climate Change Effects

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?



NASA, Global Climate Change

Paul N

Brazil faces water rationing amid worst drought in 84 years



USA TODAY
A GANNETT COMPANY

NEWS SPORTS LIFE MONEY TECH TRAVEL OPINION 41°

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

"Nuclear energy is not as risky as climate change"

by Ms Abbie Stone
30 July 2018

Climate change will disrupt energy supplies, DOE warns



US & WORLD // SCIENCE

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

go.ncsu.edu/denial (Kurtis Alexander | Aug. 3, 2018 | Updated: Aug. 3, 2018 1:05 p.m.)

Climate Change – Basics

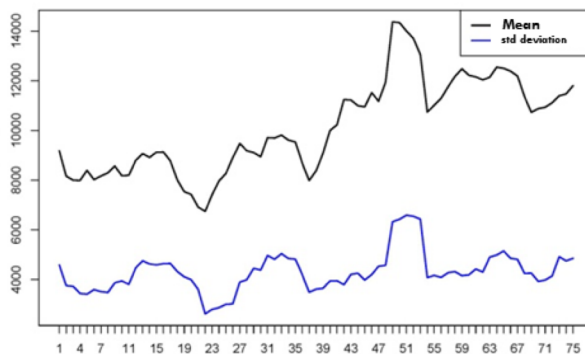
- First of all what is climate change?



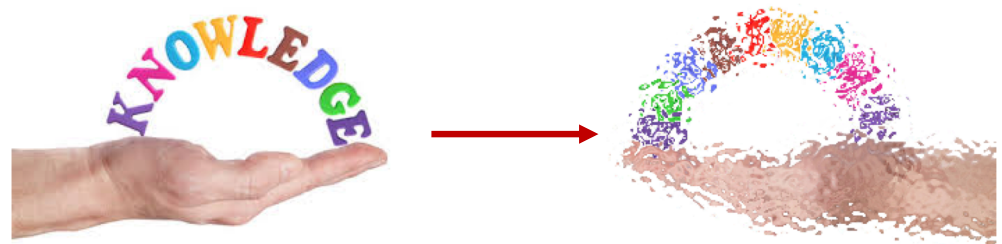
“Climate change is a **change in the statistical distribution of weather patterns** when that lasts for an **extended period of time**”

(Wikipedia, 2016)

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



4th IPCC report ← (NASA, 2016)



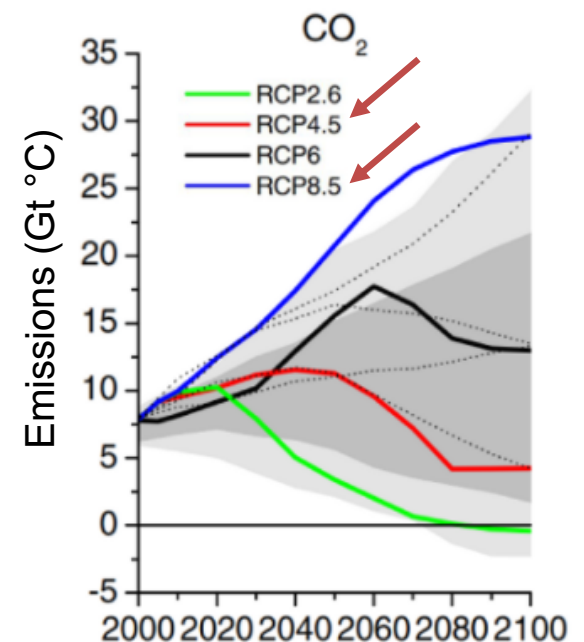
Climate change may modify our knowledge about the system

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

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

Wind speed at 100m height

Friction speed computed at 10m height

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

height in [m] of the turbine

Warm flux profile in the region (affects speed)

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

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

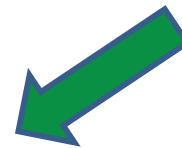
$$\Psi_S = -4.7 \frac{h}{L}$$

$$\Psi_N = 0$$



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)

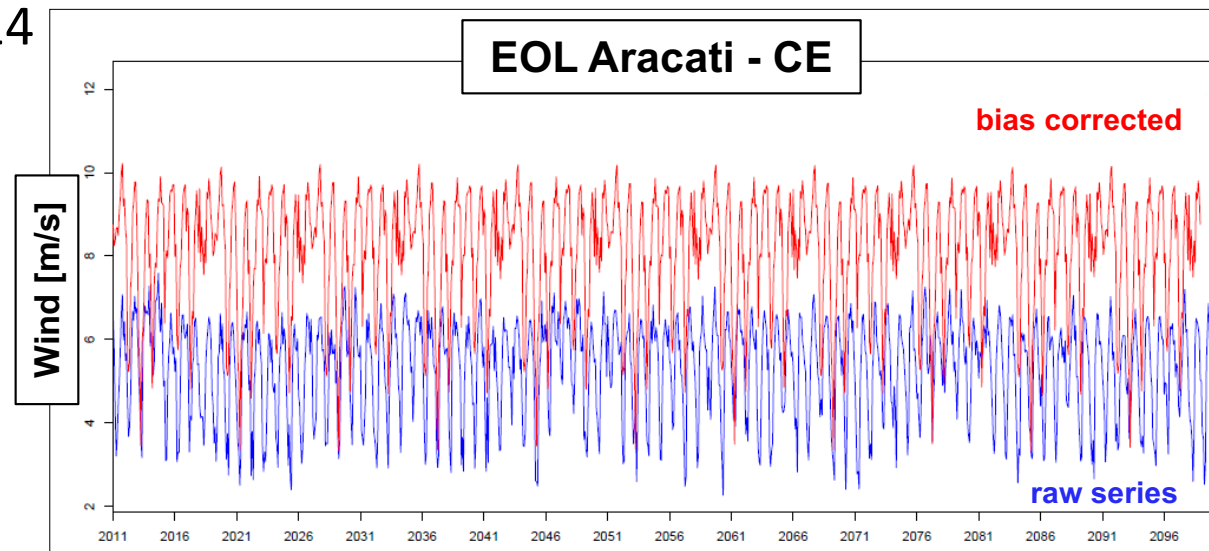
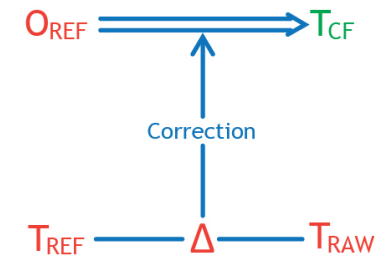
-0.03 ≤ RI ≤ 0.01 → Neutral (N)

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

(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
 - Period: 1983-1990
- The future time series is then reconstructed



Probability Distributions

- Several probability distributions (PD) were tested

- Normal or Gaussian
- Weibull
- Exponential
- Rayleigh
- Weibull

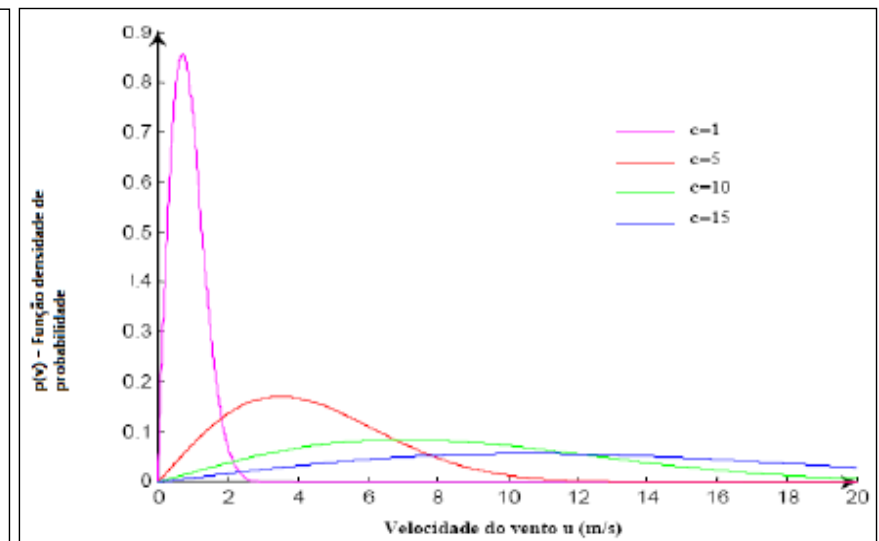
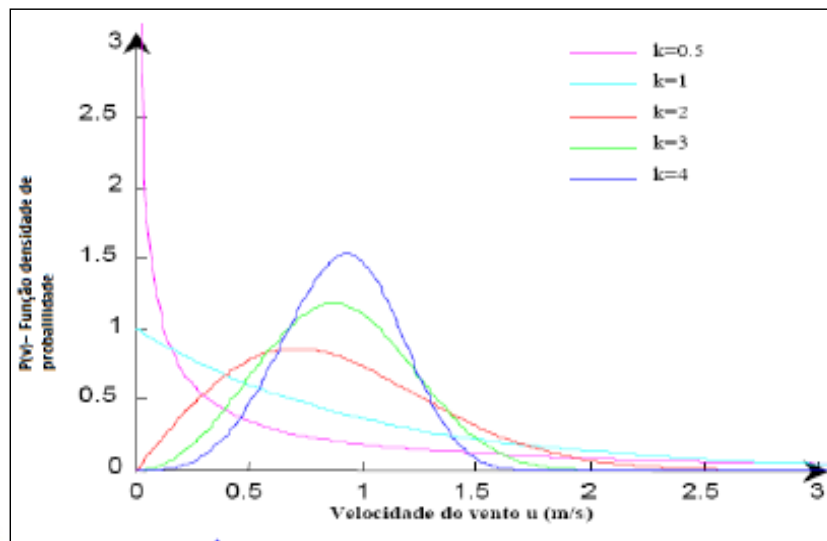
Cumulative density functions

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

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



Best to fit the data



Future Water Inflow Series from GCMs

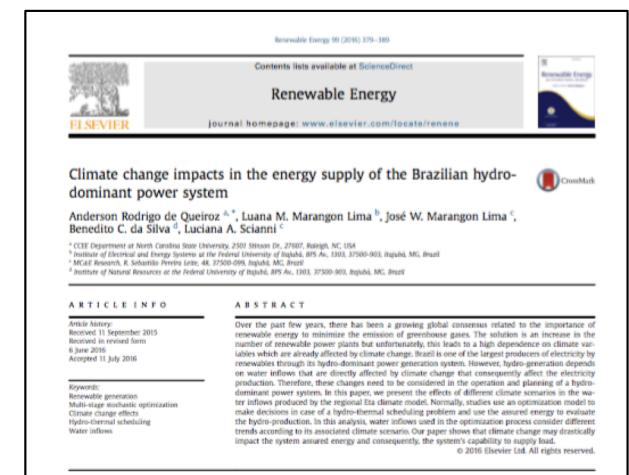
- We use the **historical inflow time series** from the Brazilian Independent System Operator (ONS)
- We build future water inflow time series using the **large hydro basins rainfall-runoff model (MGB)** (Collischonn et al., 2007)

- MGB input information:

- Climatological values
- Hydrological data
- GIS information

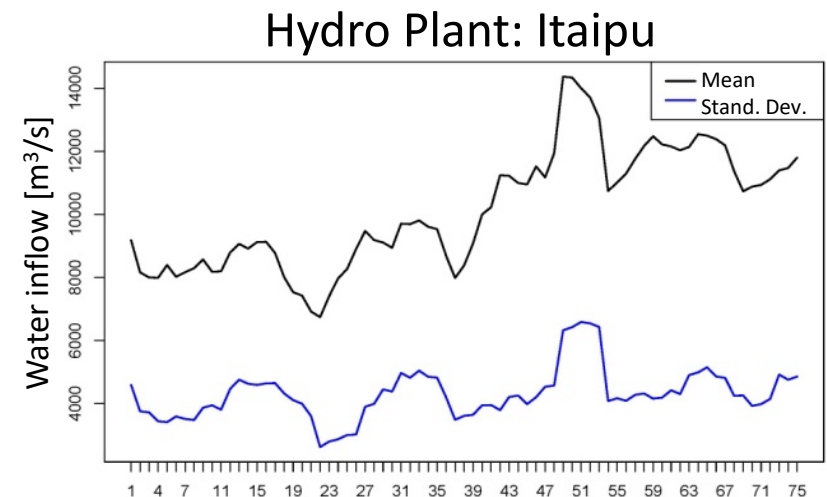
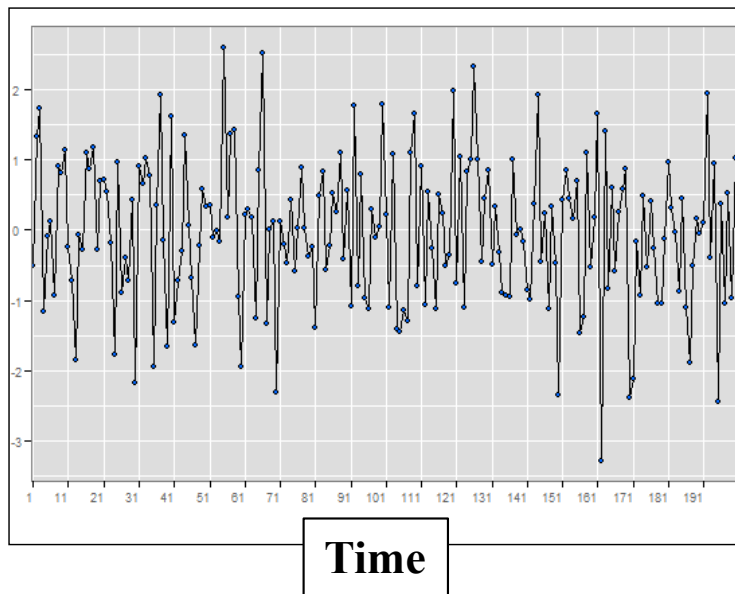
More details about the use of MGB to generate future water inflows can be found at:

*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***



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

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



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

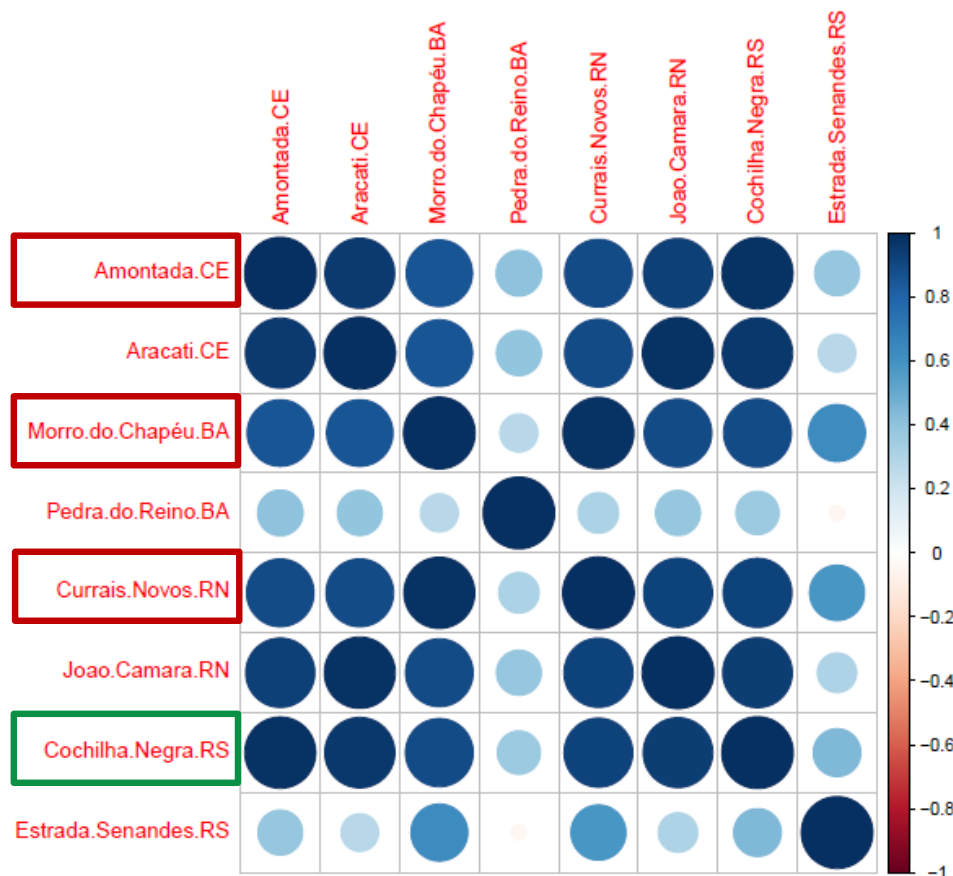
CIDADE	ESTADO
UHE Sobradinho	Northeast / S. Francisco basin
UHE Complexo Paulo Afonso	Northeast / S. Francisco basin
UHE Dona Francisca	South / Jacui basin
UHE Castro Alves	South Taq.-Antas basin

↳ Existent hydro power plants

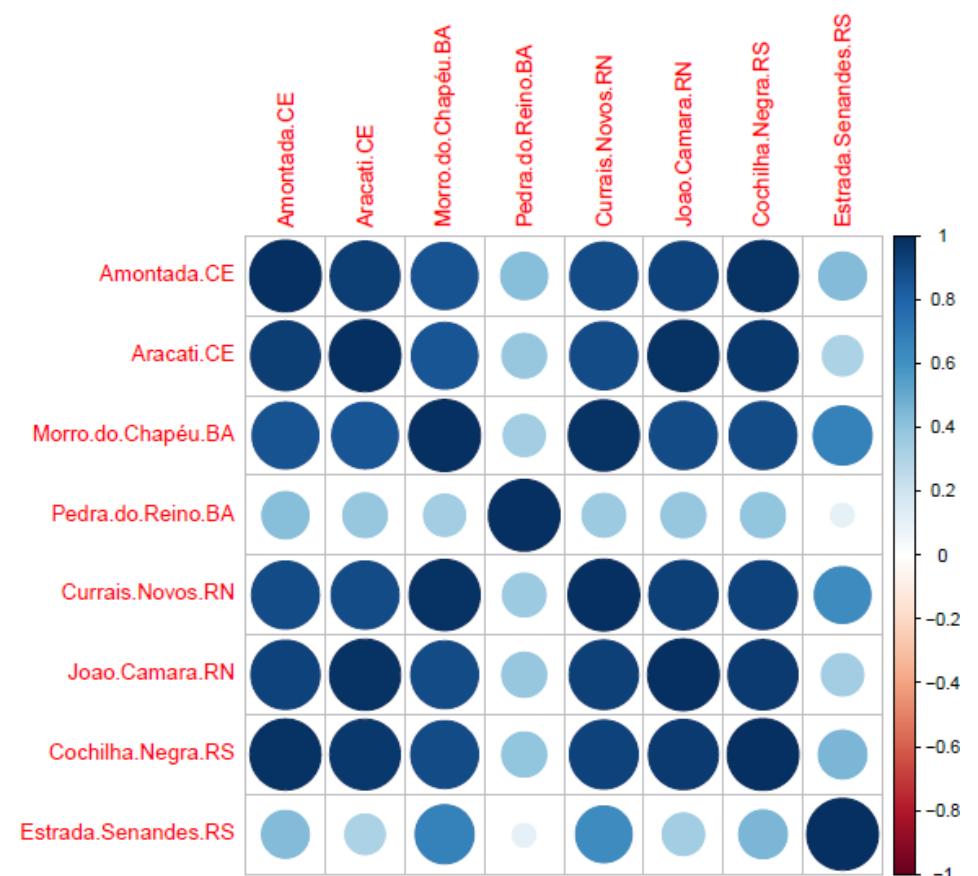
→ Projects winners of the long-term energy auctions (LER, LEN, LFA)

Witzler (2015) and EPE (2013)

Correlation Analysis – Wind Farms



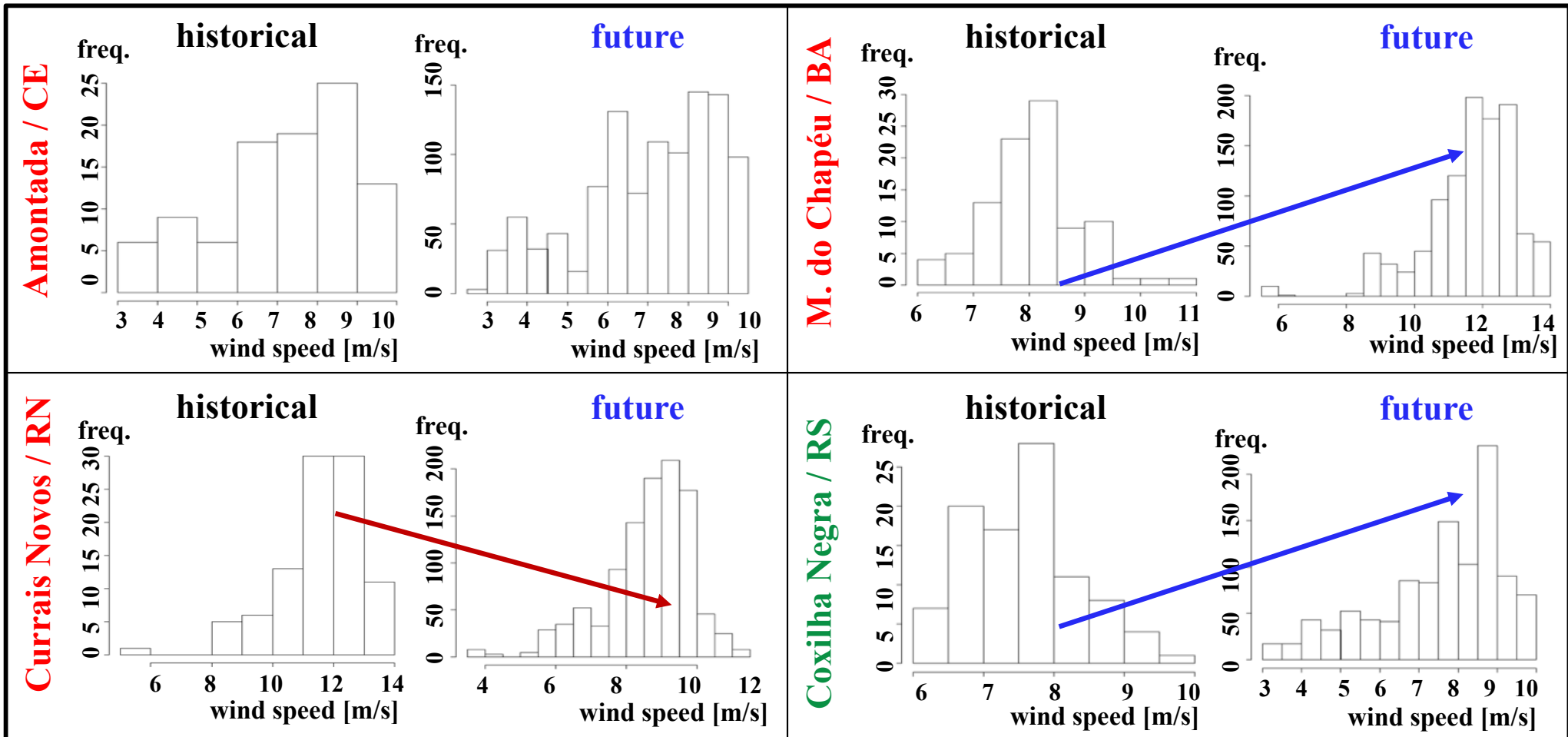
ETA-HadGEMs-ES 8.5



ETA-MIROC5 8.5

*Due to similarities we restrict the analysis

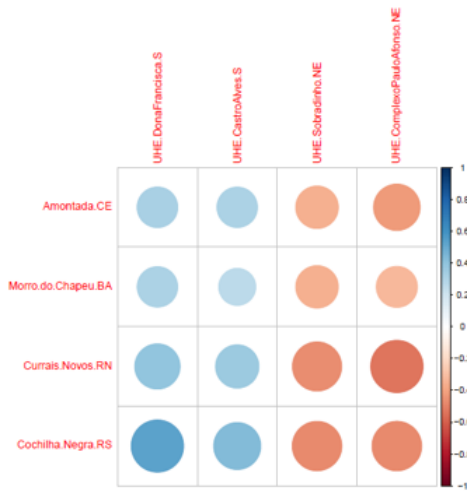
Wind Speed Histograms



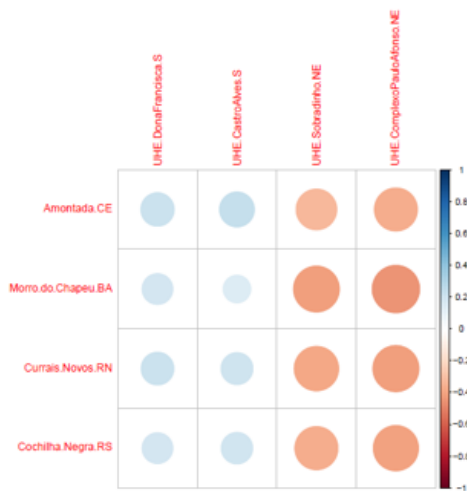
Small reduction in wind speed

Increase in speed and change of distributions shapes

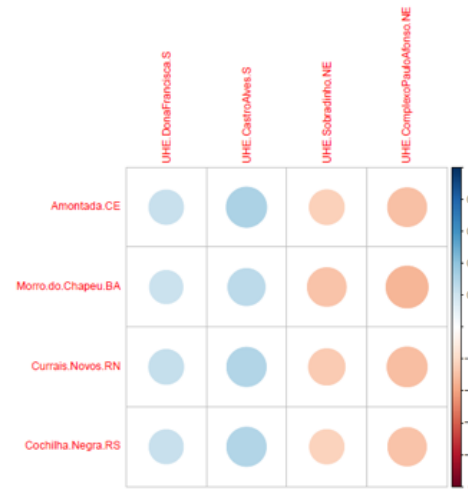
Long-term Complementary Behavior



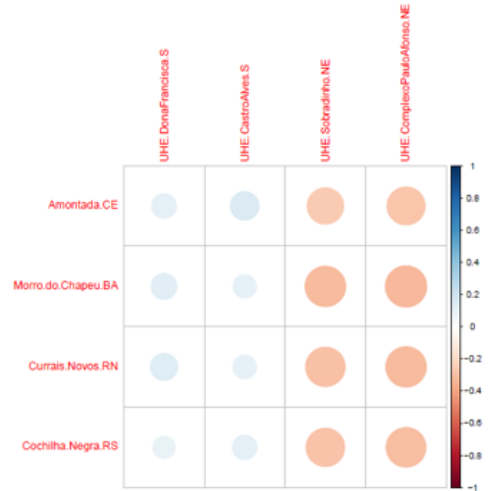
historical



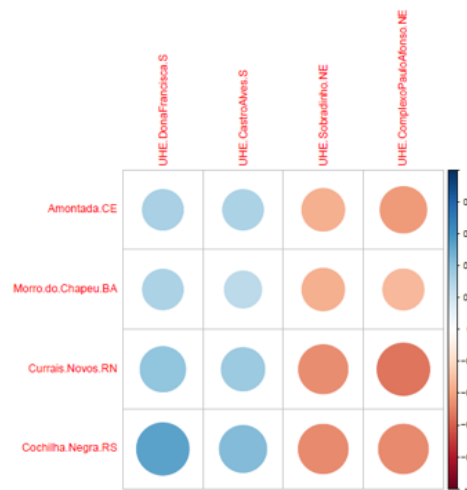
HadGEMs ES8.5 Fut 1



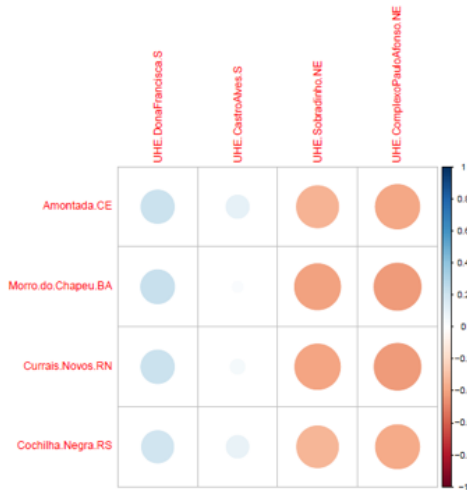
HadGEMs ES8.5 Fut 2



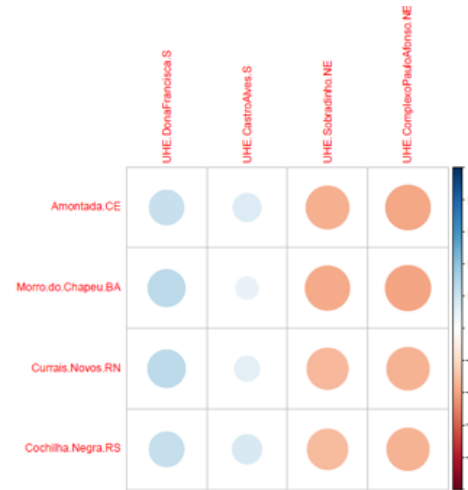
HadGEMs ES8.5 Fut 3



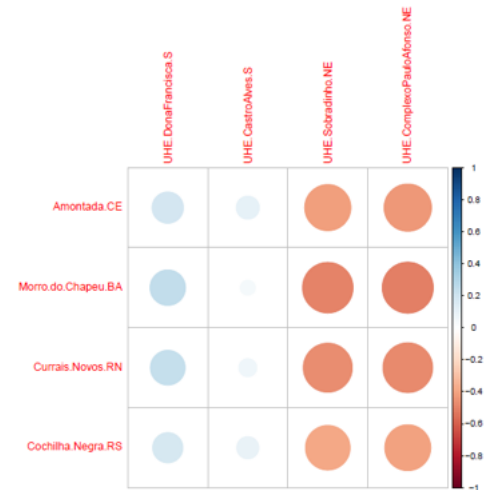
historical



Eta - Miroc 8.5 Fut 1

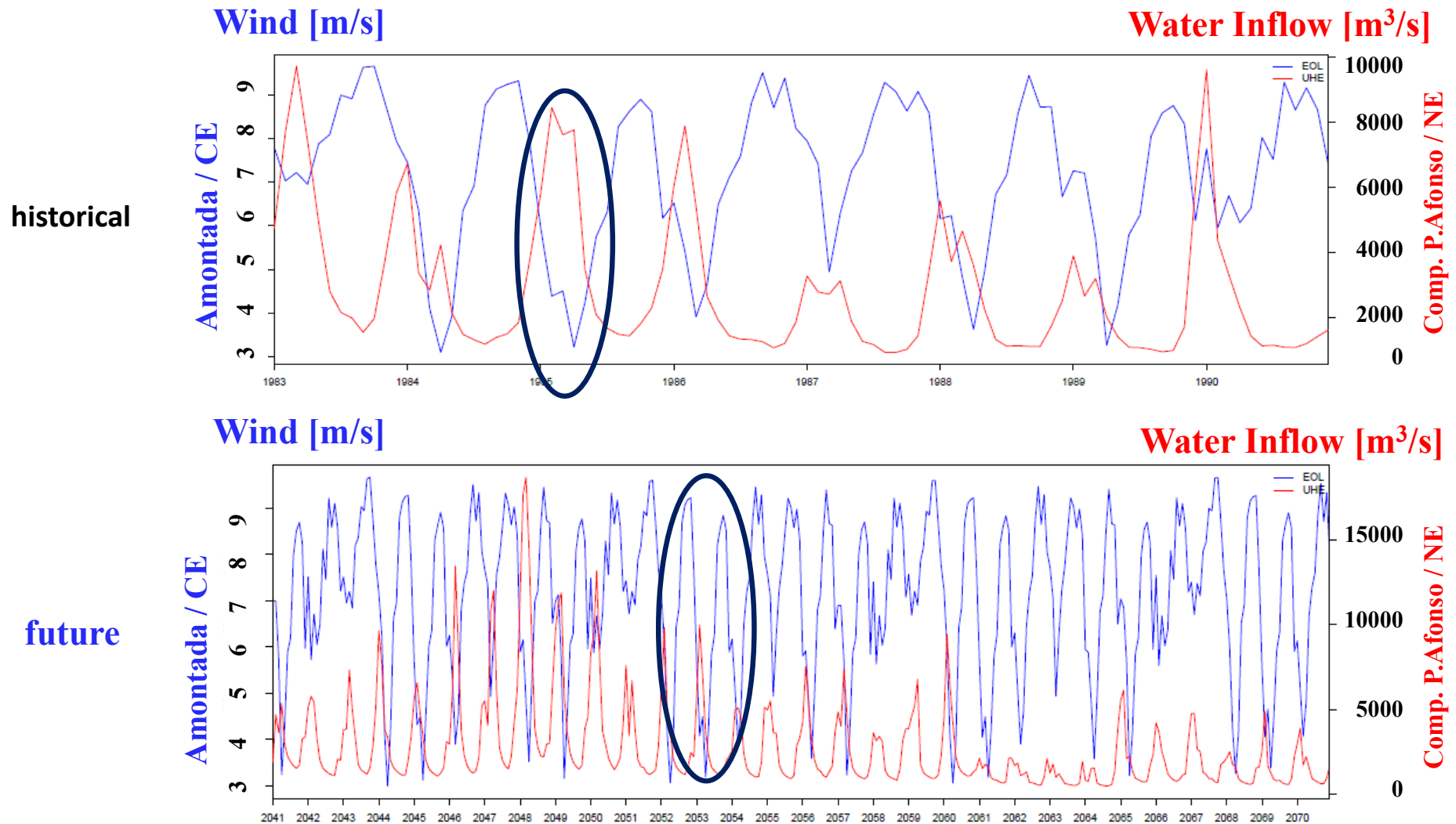


Eta - Miroc 8.5 Fut 2




Eta - Miroc 8.5 Fut 3

Future Wind and Water Inflow Series



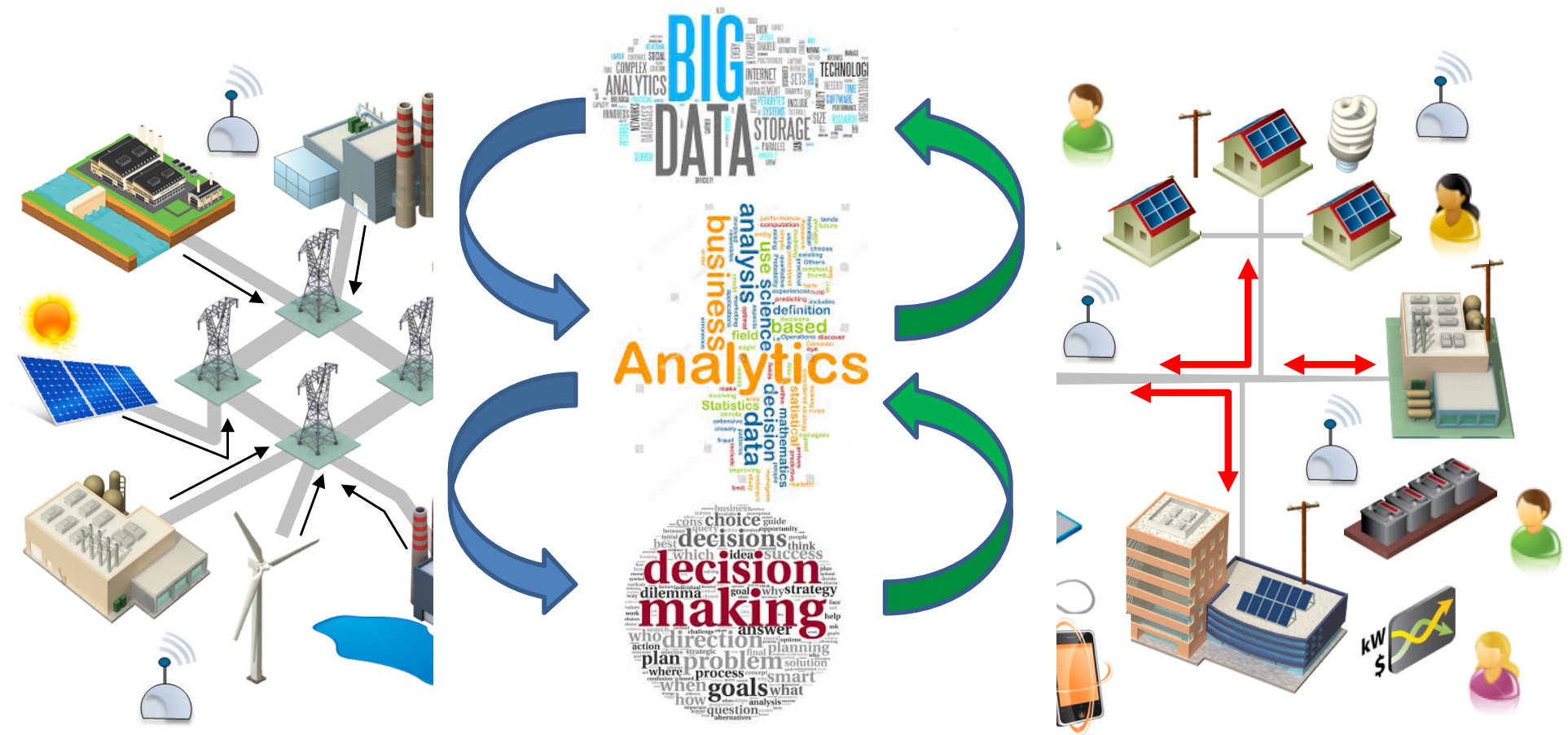
ETA-HadGEMs-ES 8.5

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

Final Comments - Integrated Vision



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



Thank You !

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