THE MANAGEMENT OF ELECTRICAL SYSTEMS WITH VARIABLE GENERATION AT GREAT SCALE.

The case of Uruguay

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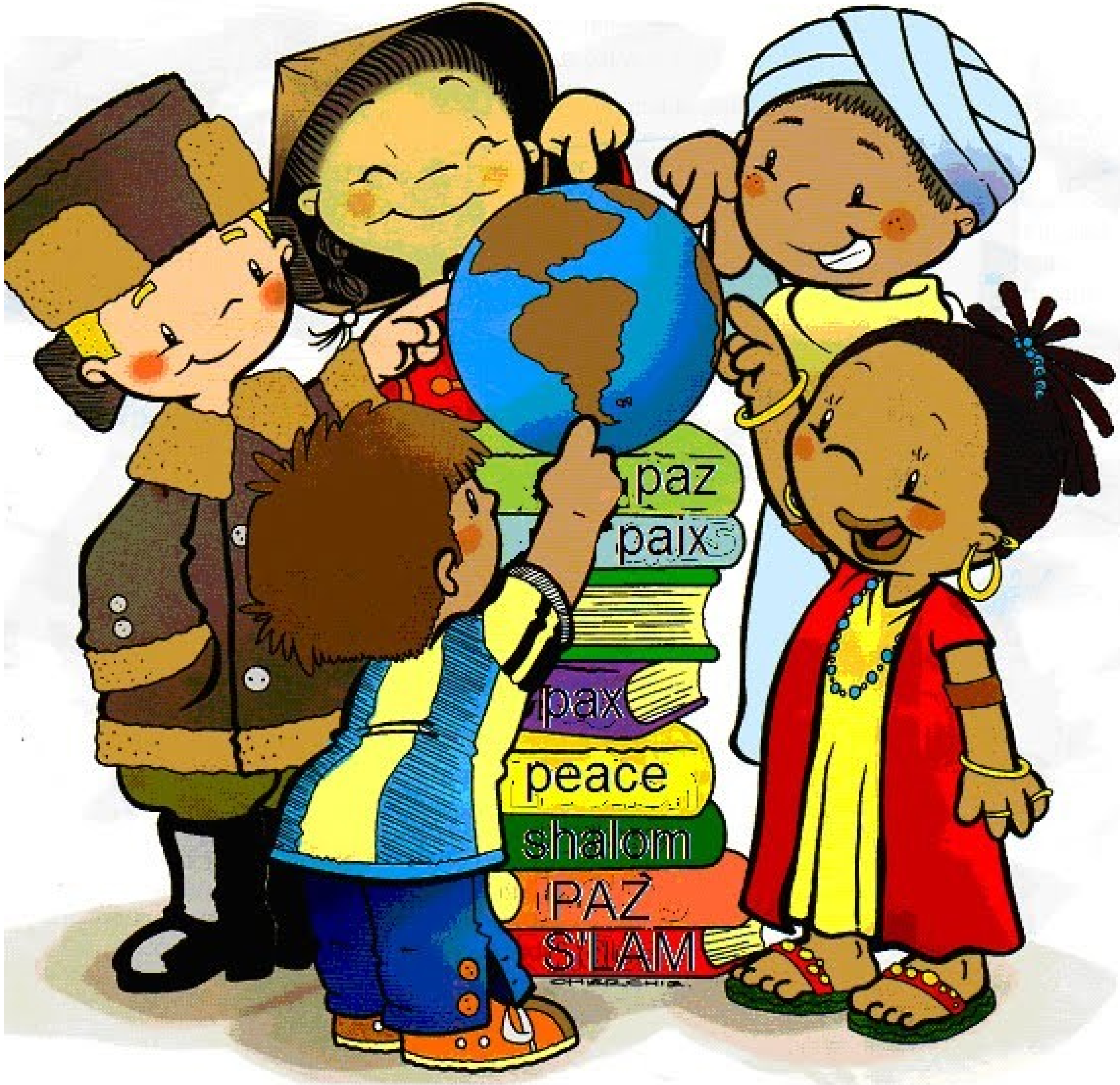
México WindPower 4-5 de Marzo de 2020

Mexico WindPower
EXPOSICIÓN y CONGRESO
4 - 5 MARZO 2020
Centro Citibanamex, CDMX
Organizado por: amdee Asociación Mexicana de Energía Eólica, GWEC, Tarsus



Each system has its peculiarities.

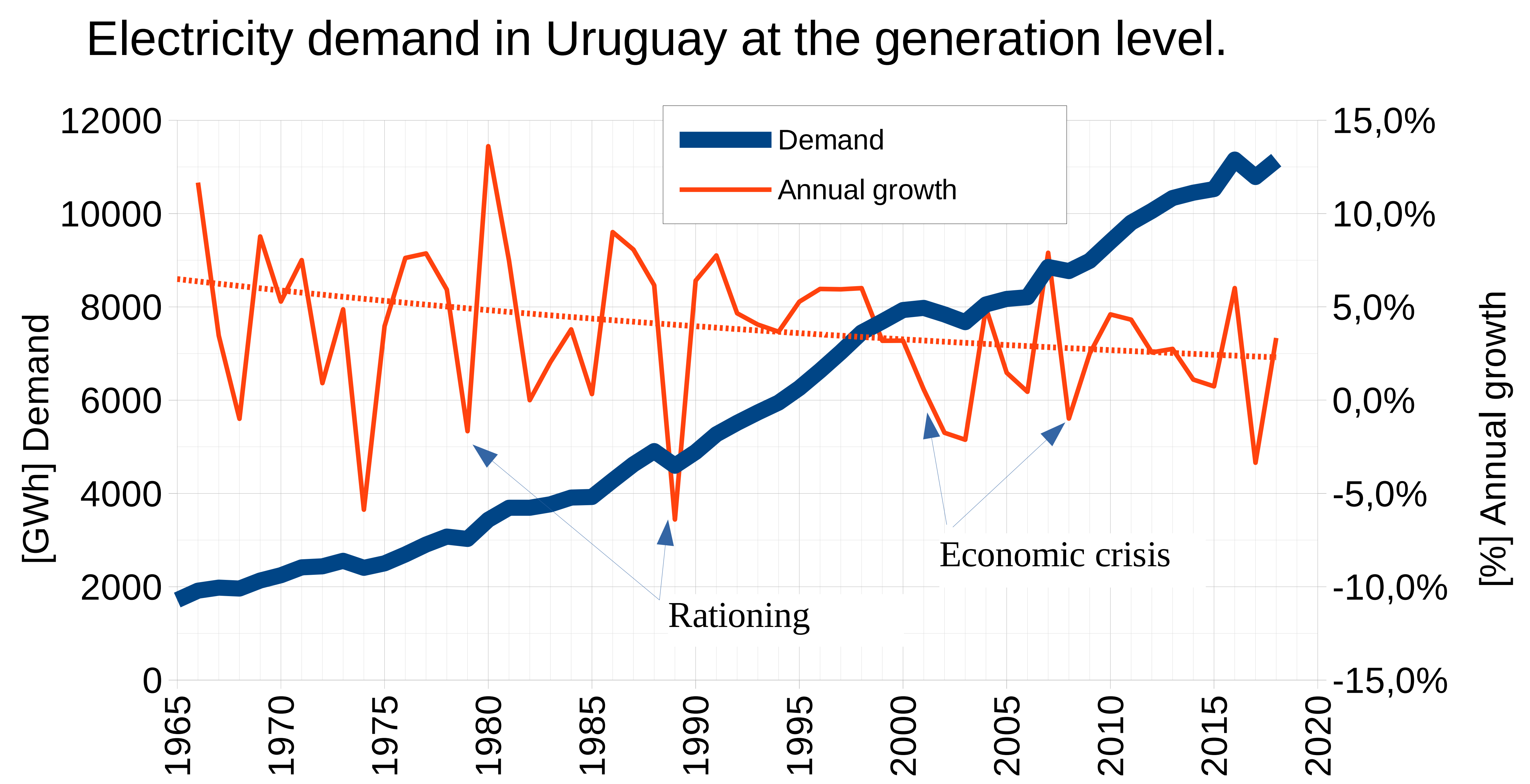
The optimal solution is surely different for each country.

In this presentation we will show how the Operation of the National Integrated System in **Uruguay** is carried out with an installed wind and solar capacity that exceeds the peak of the system load in 70% of the days of the year

República Oriental del URUGUAY

Area 176.215 km^2
Population[1] 3.450.000 inhab
Pop. Density 19 inhab/km^2
GPD[2] 59.6 USD Billions
GPD/inhab[3] 14 600 USD/inhab
HDI[4] 0.808 (position 57/189)

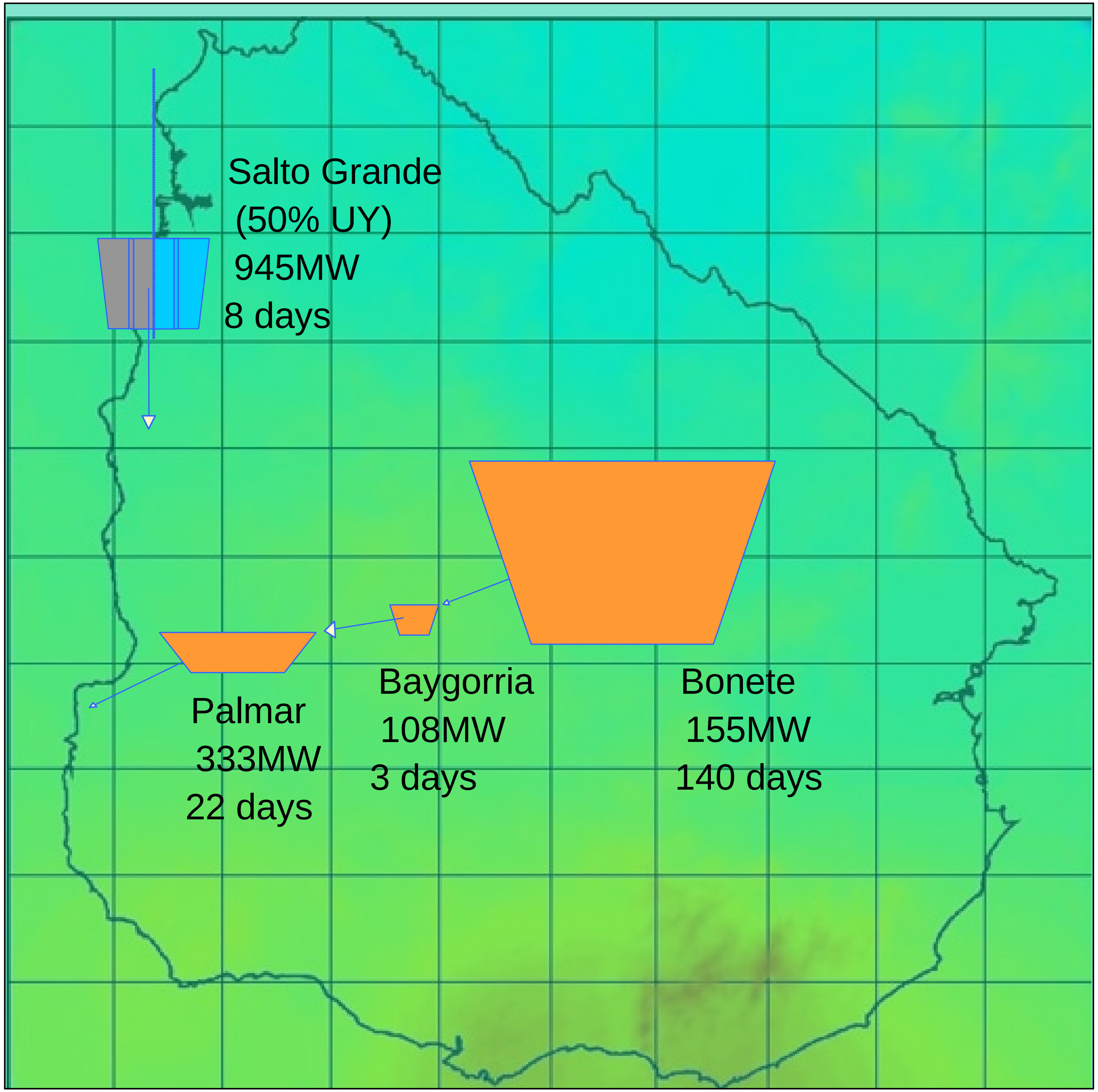
[1] Estimated 2018
[2] Gross National Product 2018
[3] Year 2018
[4] Human Development Index 2019



Electricity demand in Uruguay at the generation level.
Demand
Annual growth
[GWh] Demand
[%] Annual growth
12000
10000
8000
6000
4000
2000
0
15,0%
10,0%
5,0%
0,0%
-5,0%
-10,0%
-15,0%
1965
1970
1975
1980
1985
1990
1995
2000
2005
2010
2015
2020
Rationing
Economic crisis

Uruguay 2010
Hydroelectric: 1541 MW

- No place left for large hydro projects
- A potential of 200 MW is estimated in mini and micro projects.
- Accumulation and pumping projects identify 3 locations of about 100 MW x 6 hours



Fuel fired generators (2010).

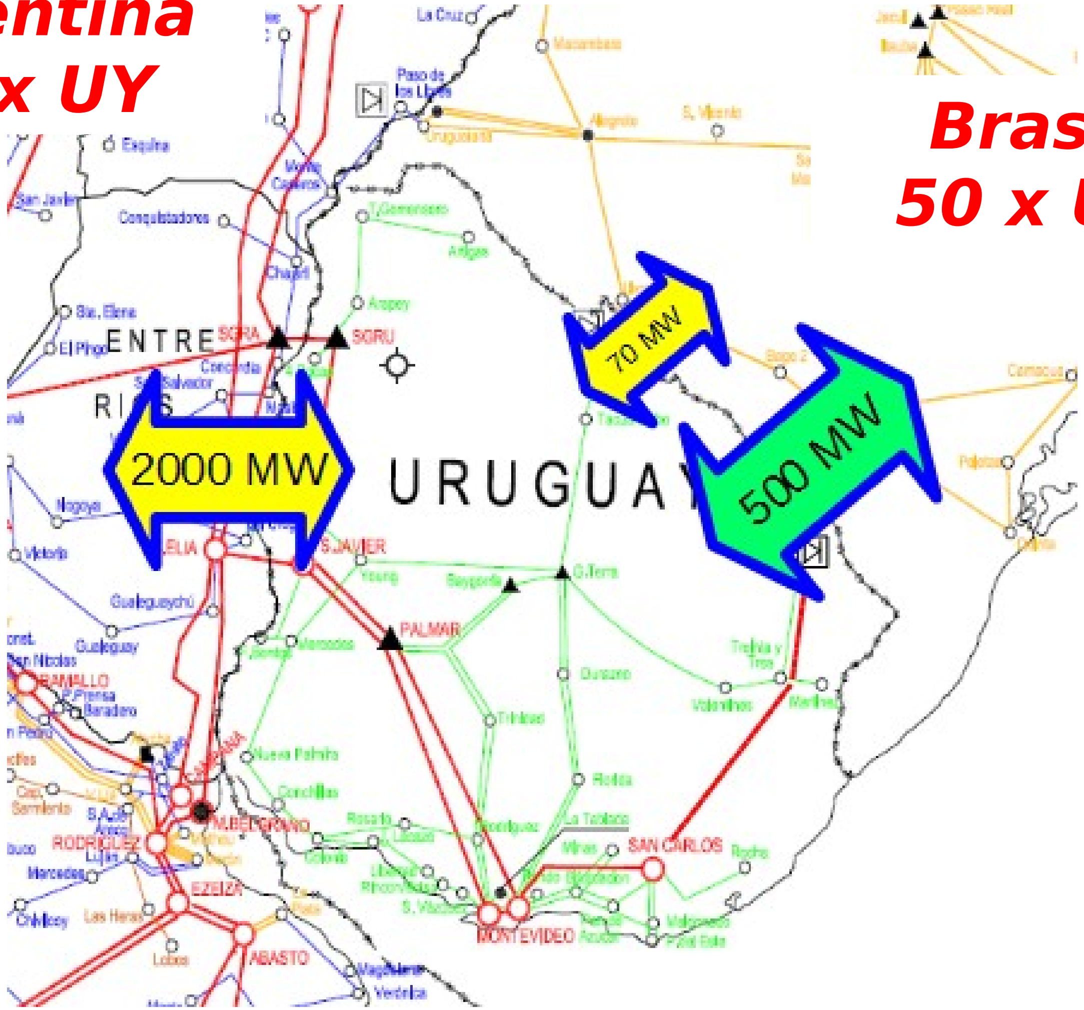
- 70 MW of engines burning fuel oil
- 220 MW of heavy duty turbines burning diesel.
- 300 MW of high performance turbines burning diesel or natural gas.

****

- 590 MW Total thermal capacity (2010)

The neighborhood (2010).

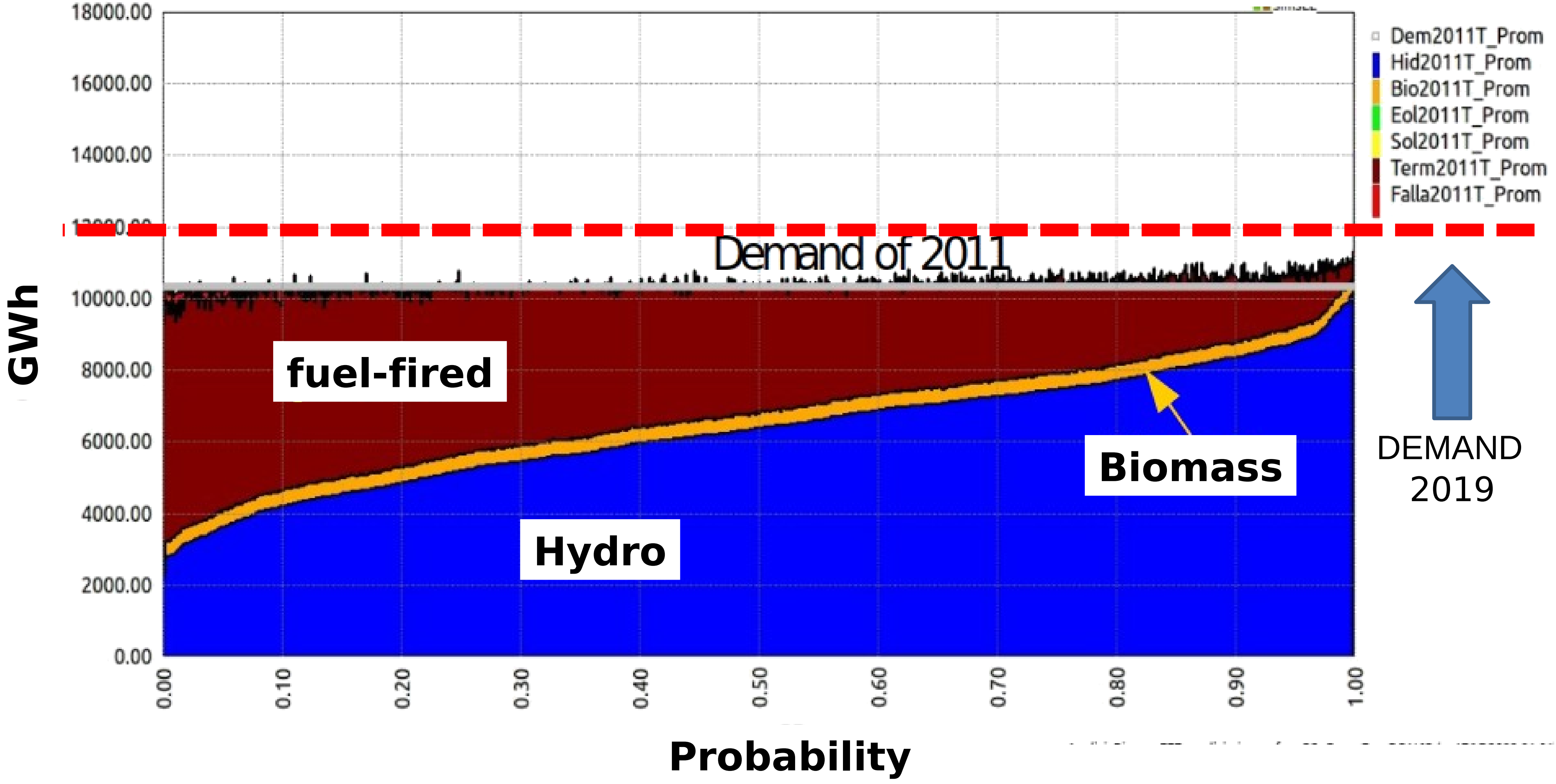
Argentina
11 x UY



Brasil
50 x UY

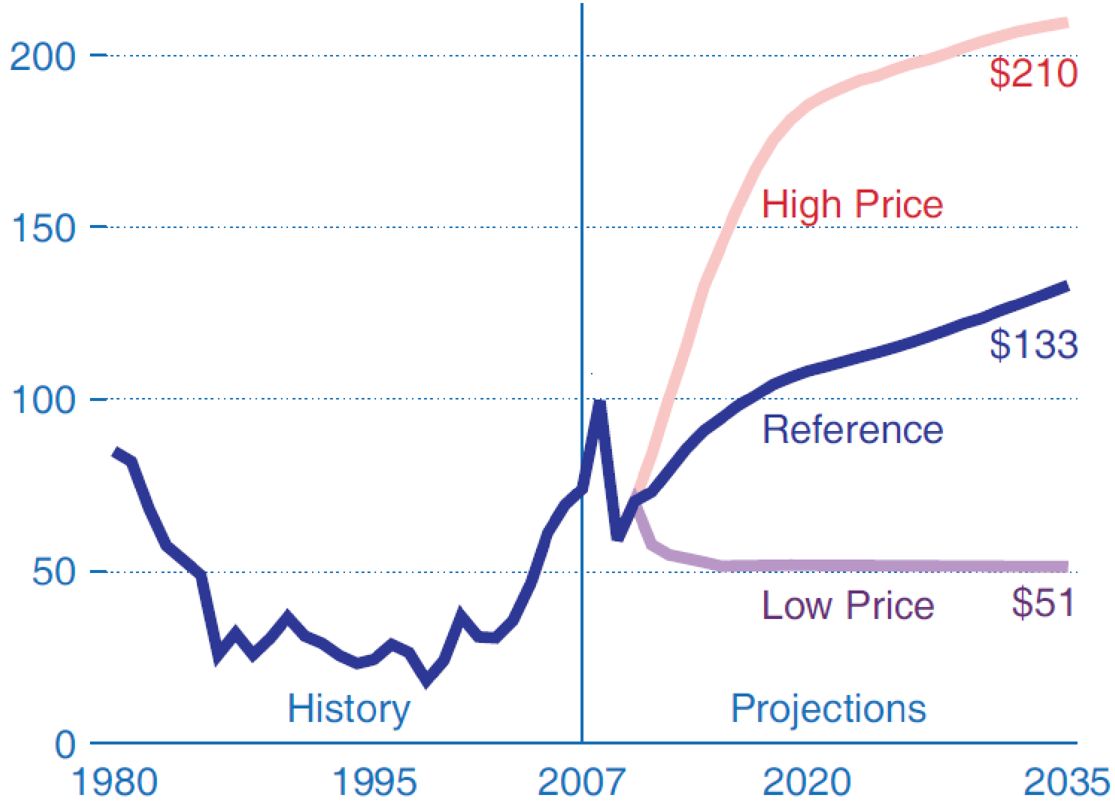
- Uruguay does not have proven reserves of oil or natural gas.
- Natural gas, if available, comes from Argentina by pipeline. Historical availability has been very low since Argentina has experienced a lack of natural gas for its own consumption.
- This situation could change in the future if the Vaca Muerta project is developed.

Risk picture Uruguay-2011-> 2019



Projection of the price of a barrel of oil.
mmm ... more uncertainty than renewables !!!

Figure 32. World oil prices in three cases, 1980-2035 (2008 dollars per barrel)



U.S. Energy Information Administration / International Energy Outlook 2010

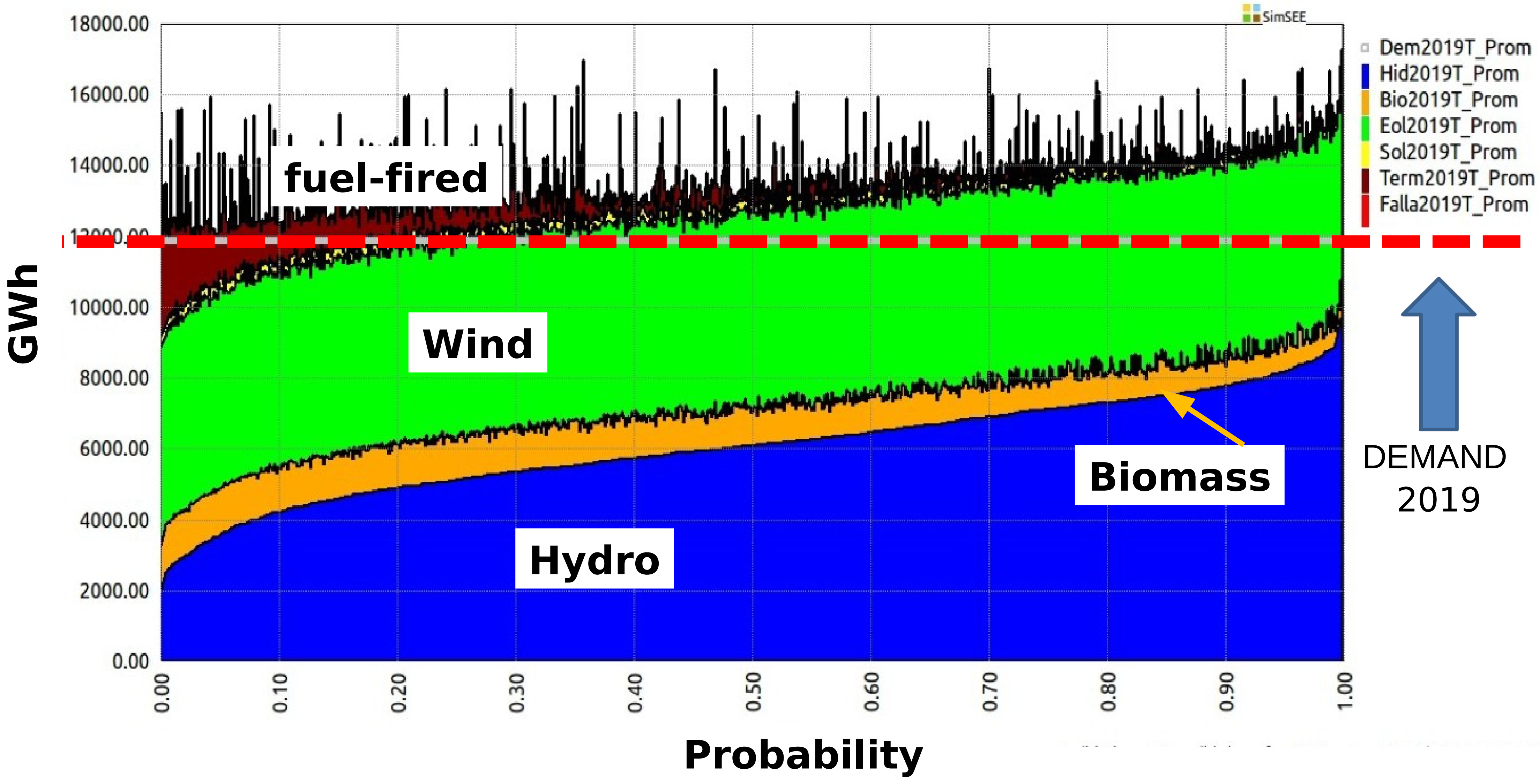
Nobody knows
where the world goes

2010 Thermal Energy risk

Volume: from 0 to 75% of annual Demand
Price : from 51 USD/bbl to 210 USD/bbl

- The need for change in the electricity generation matrix.

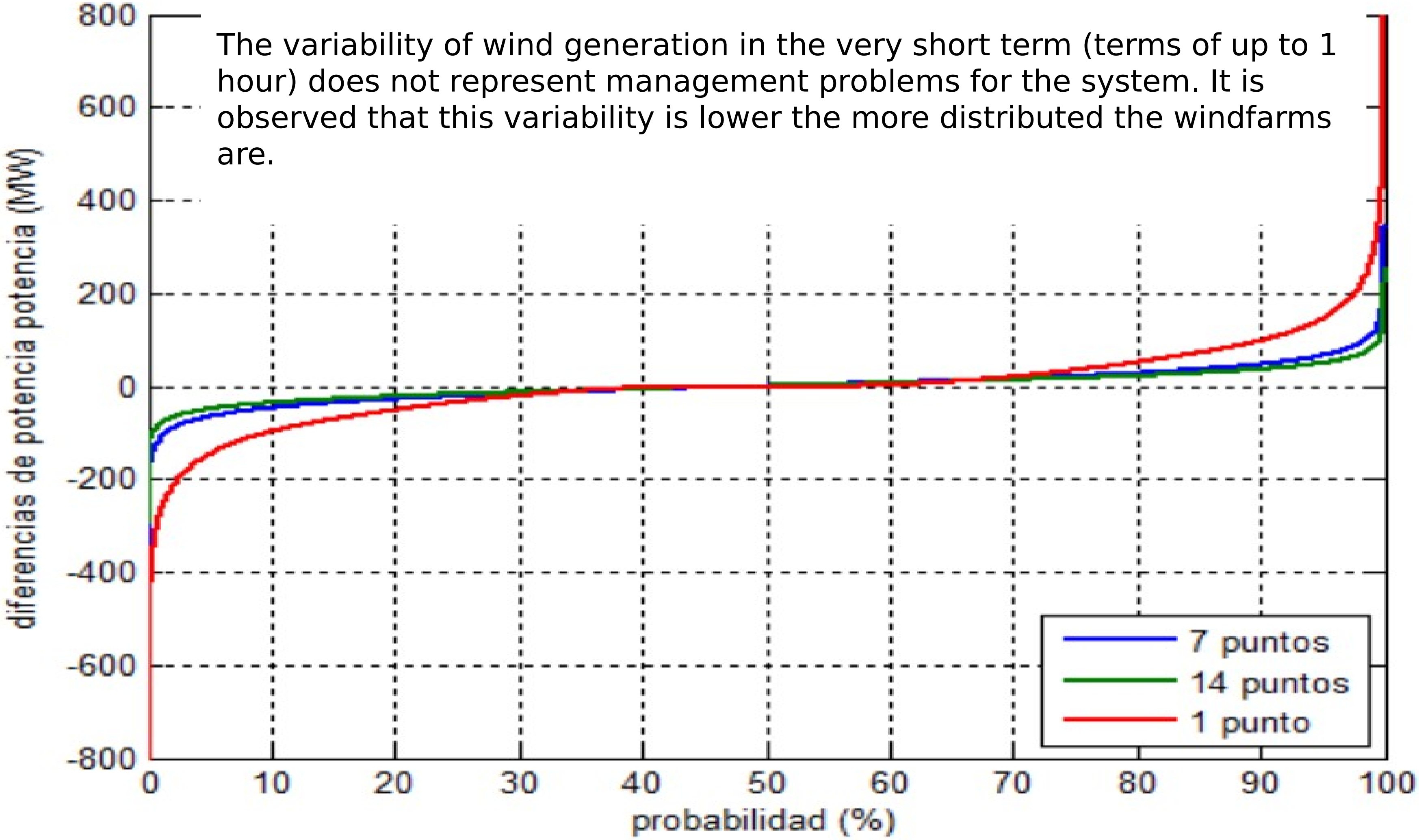
2019 Simulation.



Geographic Filtering

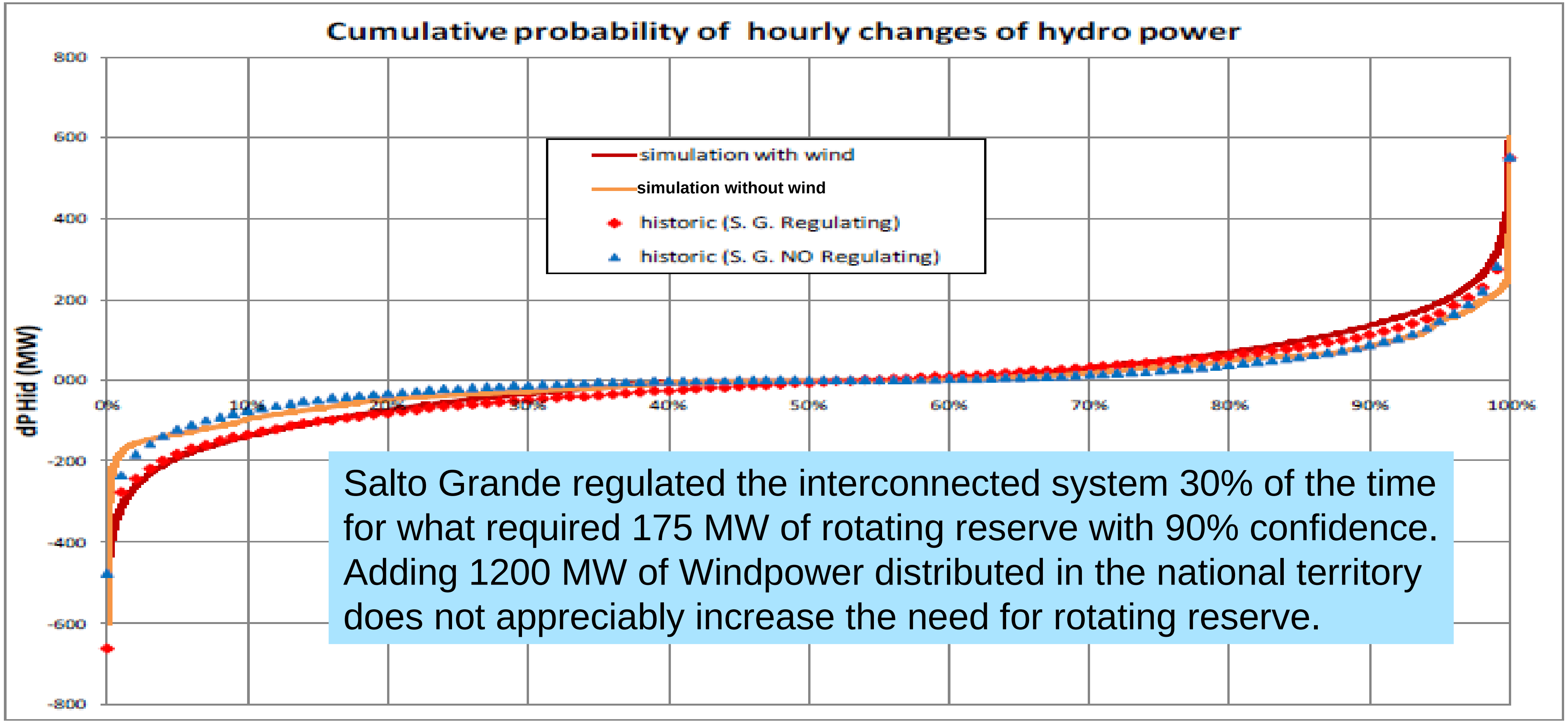
VERY SHORT VARIABILITY (10min-1 hour)

(600 MW, simulation 2011 based on wind measurement series.)



The variability of wind generation in the very short term (terms of up to 1 hour) does not represent management problems for the system. It is observed that this variability is lower the more distributed the windfarms are.

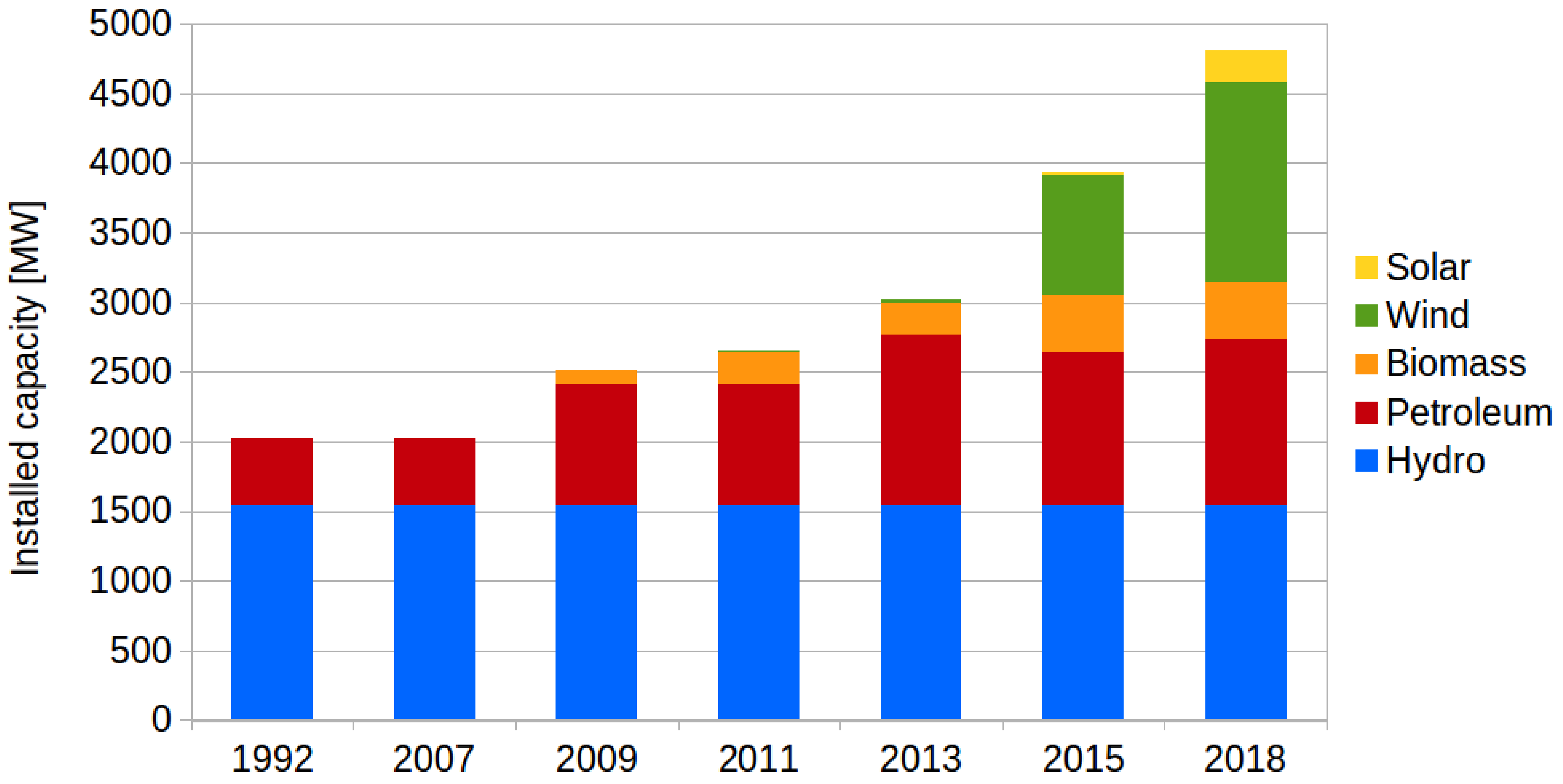
Study: “Salto Grande” controlling the frequency of Uruguay+Argentina vs. Controlling the frequency of Uruguay with and without 1200 MW of wind



Salto Grande regulated the interconnected system 30% of the time for what required 175 MW of rotating reserve with 90% confidence. Adding 1200 MW of Windpower distributed in the national territory does not appreciably increase the need for rotating reserve.

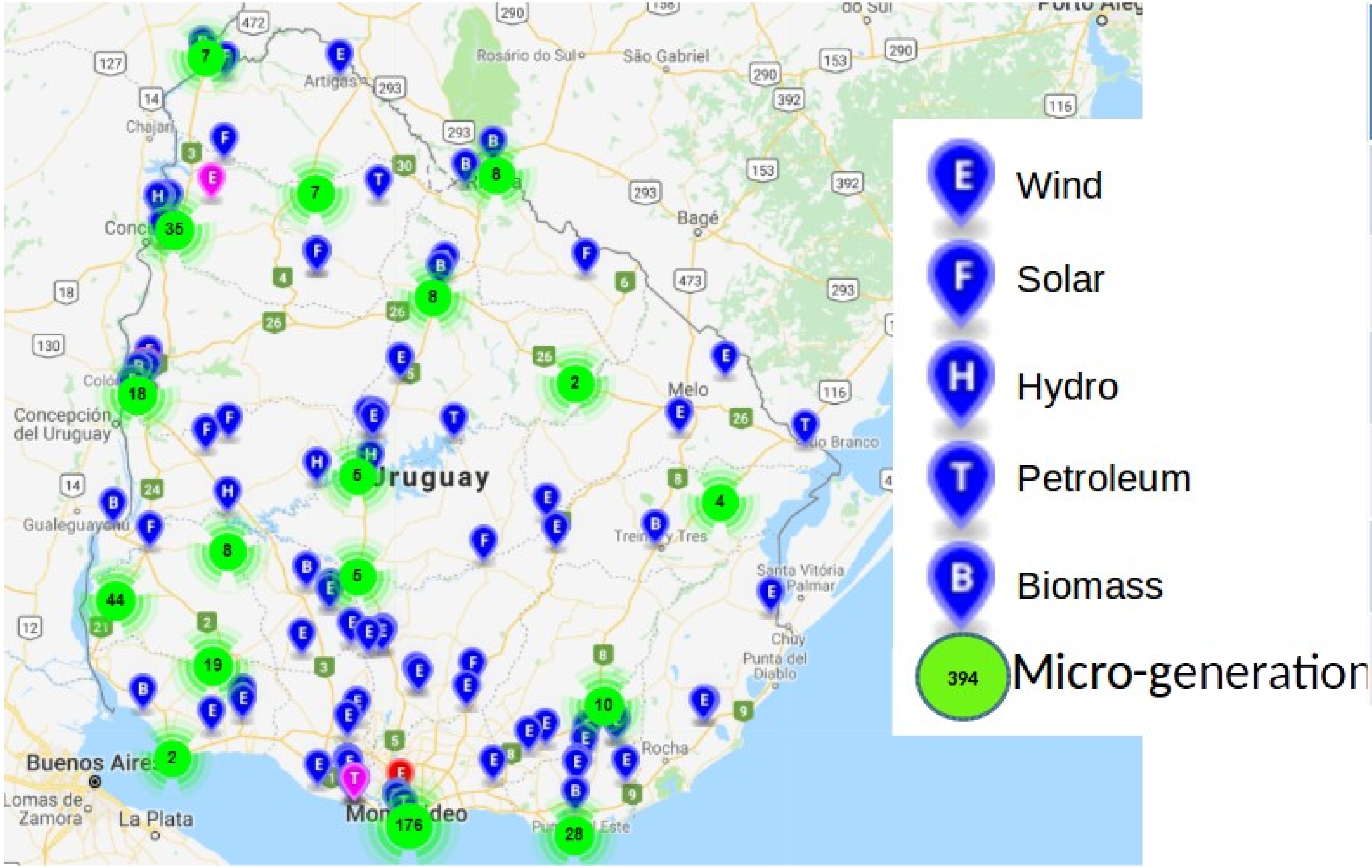
Modeling and simulation of the power energy system of Uruguay in 2015 with high penetration of wind energy. Ruben Chaer, Eliana Cornalino, Enzo Coppes
Simpósio de Especialistas en Planejamento da Operaçâo e Expansâo Elétrica, XII SEPOPE. Rio de Janeiro, RJ, Brasil, page SP082 - 2012

Installed capacity



Expected Demand: Peak: 2000 MW energy: 12000 GWh

Uruguay 2018 Generators

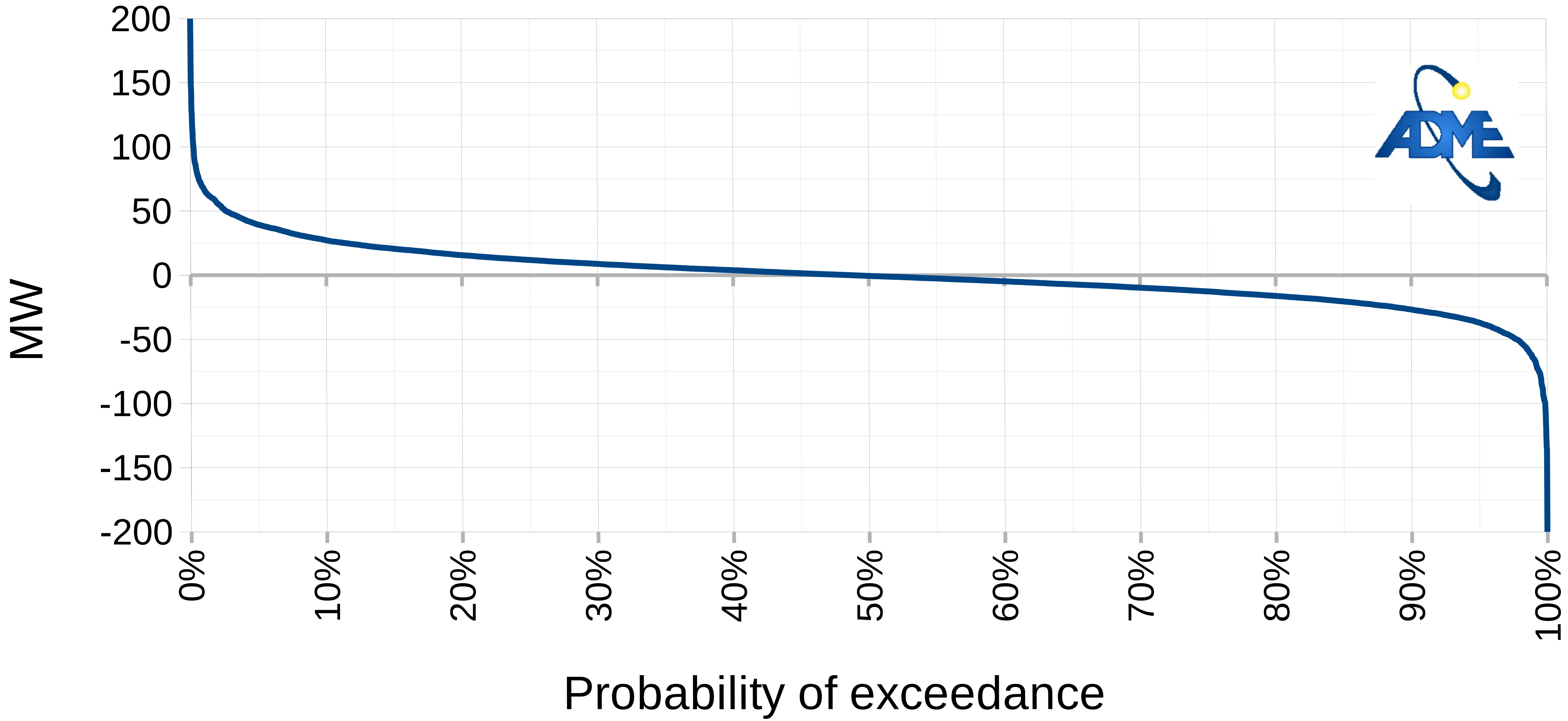


4812 MW
1432
226
1538
1191
413
12

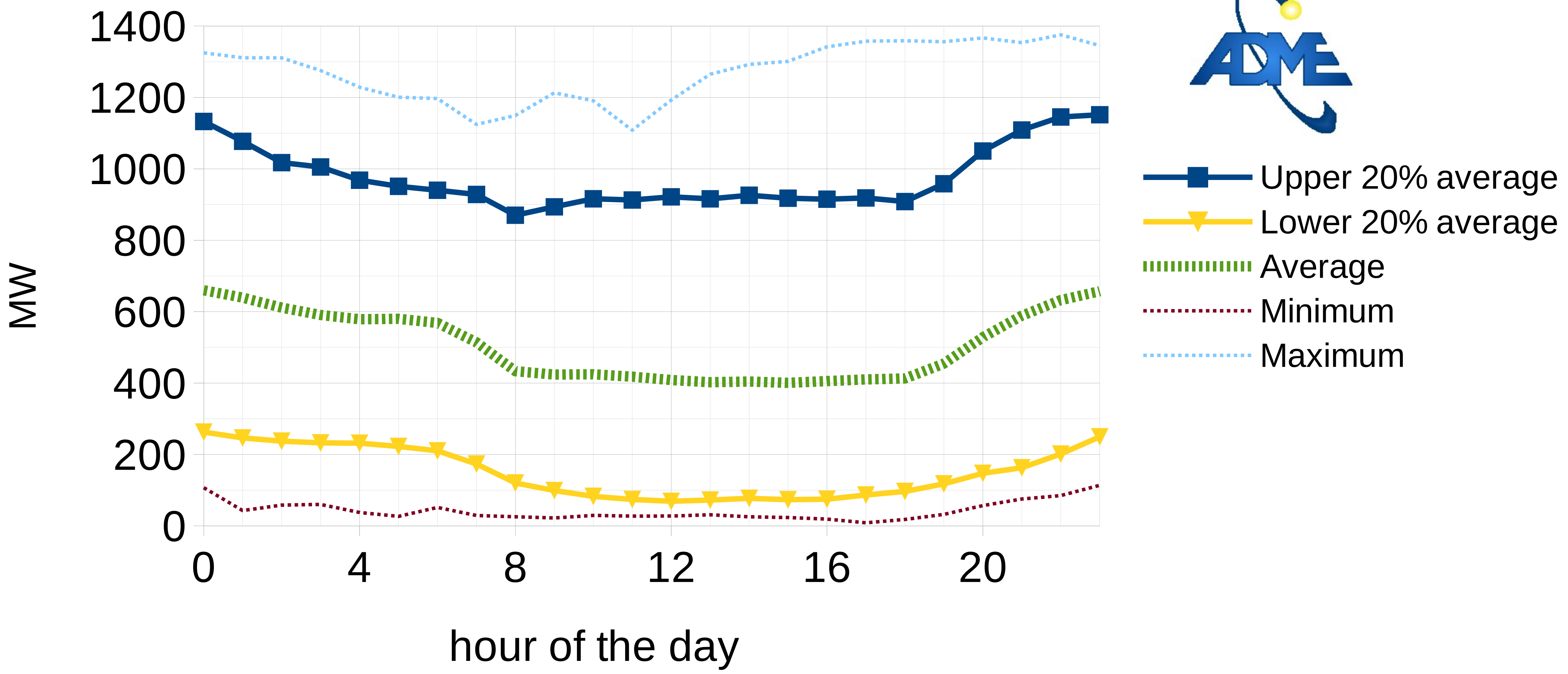

2011 Design


2018 Verified
AB

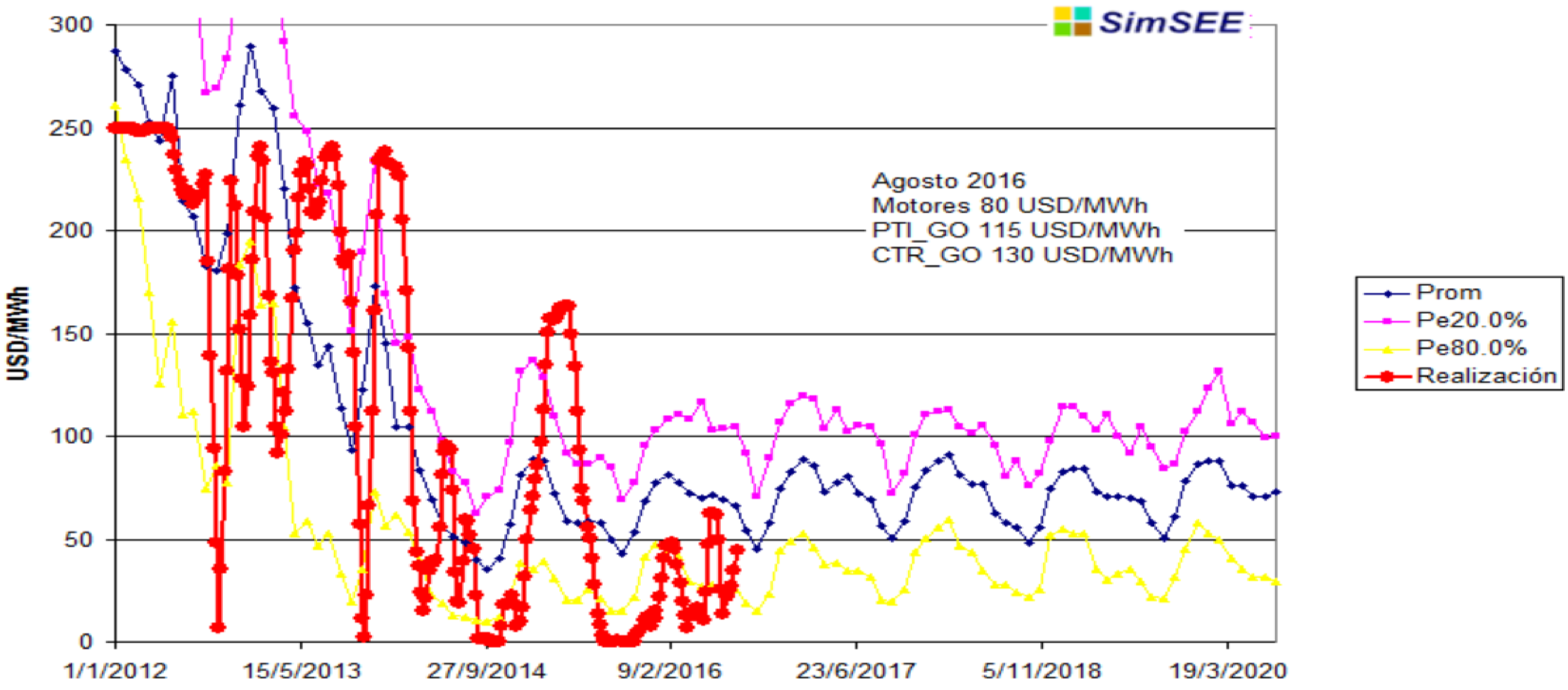
Distribution of the wind generation variation tenminutal verified in Uruguay from 1/1/2019 to 3/17/2019 (1482 MW installed)



hourly verified distribution of tenminutal wind generation in Uruguay from 1/1/2019 to 3/17/2019 (1482 MW installed)



Proyección de marginales según simulación realizada en Abril 2012 vs. Realización histórica hasta agosto 2016.



Requerimientos a los generadores, compromisos del operador de la red y potestades de ADME.

En Uruguay estos requerimientos y compromisos se reflejan en los Convenios de Uso de la red eléctrica.

Ejemplo de Convenio de Uso entre Generador y Operador de la Red:

https://portal.ute.com.uy/sites/default/files/docs/Contrato%20CVEE%2031-8-2017%20Estrellada.pdf

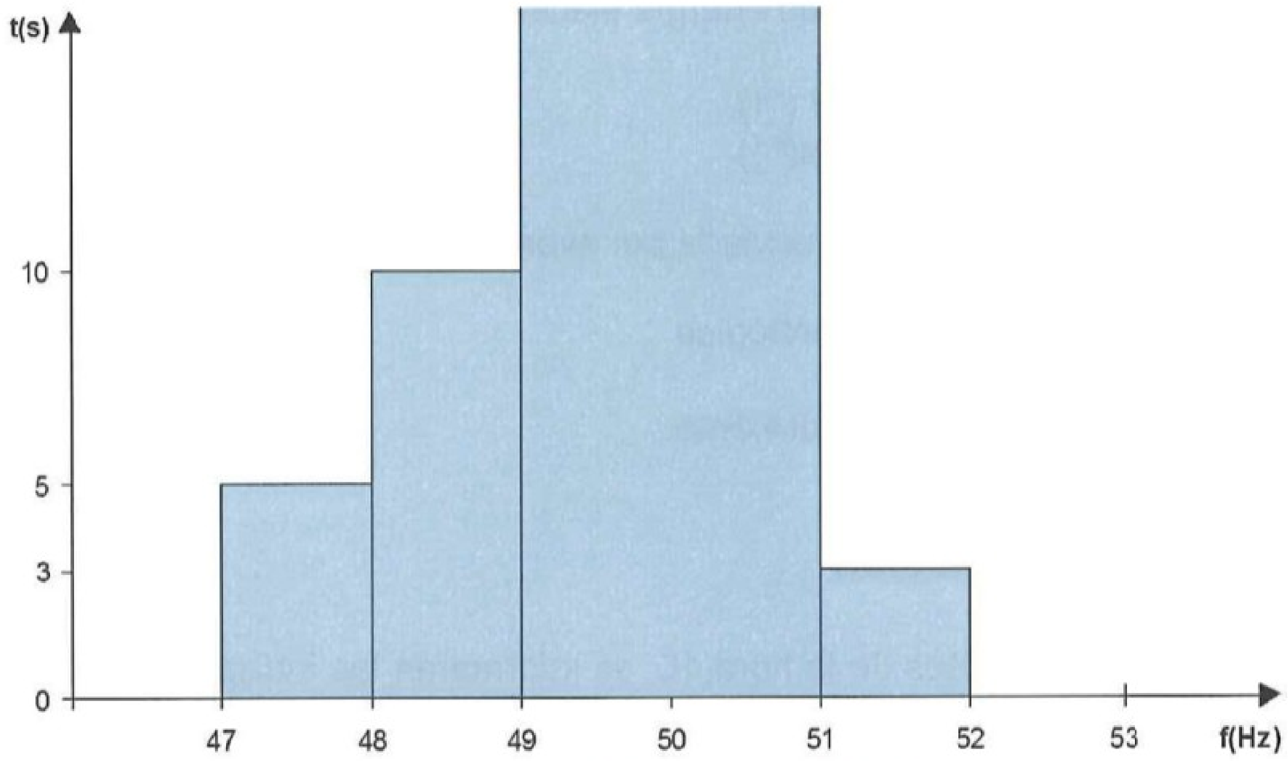
Disponibilidad comprometida del Nodo de conexión.

Indicador	NODO DE CONEXIÓN en 150 kV o menos	NODO DE CONEXIÓN en 500kV
$\overline{Tc}_i$	36	26

- Tc = Tiempo De Corte en Horas a partir del cual el Operador de la Red debe compensar al generador.
  - La compensación se calcula como la energía que hubiera entregado de acuerdo al promedio histórico de genreación del último semestre multiplicada por el precio medio recibido en las horas de corte que exceden el valor Tc.

Compromiso del Generador (f)

Las unidades generadoras deberán estar diseñadas para una frecuencia nominal del sistema de 50 Hz, y permanecer conectada al SIN, ante la ocurrencia de eventos de frecuencia según se indica en la Figura 1, donde se establecen los tiempos mínimos de permanencia.



Para el rango de frecuencia entre 49 y 51 Hz la CENTRAL GENERADORA deberá permanecer permanentemente conectada a la RED DE UTE.

Compromiso del Generador Estatismo y dP/dt

Los controles de potencia activa de las unidades generadoras deberán cumplir los siguientes requisitos:

a) Estatismos con valores entre 0 y 10 % para frecuencias entre 47 y 52 Hz, cambiables bajo carga
b) La velocidad de respuesta deberá poder ajustarse entre 1 y 10 % de la potencia nominal de la unidad generadora por segundo.

Control de potencia activa.

El ajuste del control de potencia activa – frecuencia se aplicará para el rango entre 50 y 52 Hz, tal como se muestra en la Figura 2, y el mismo será definido por el DNC.

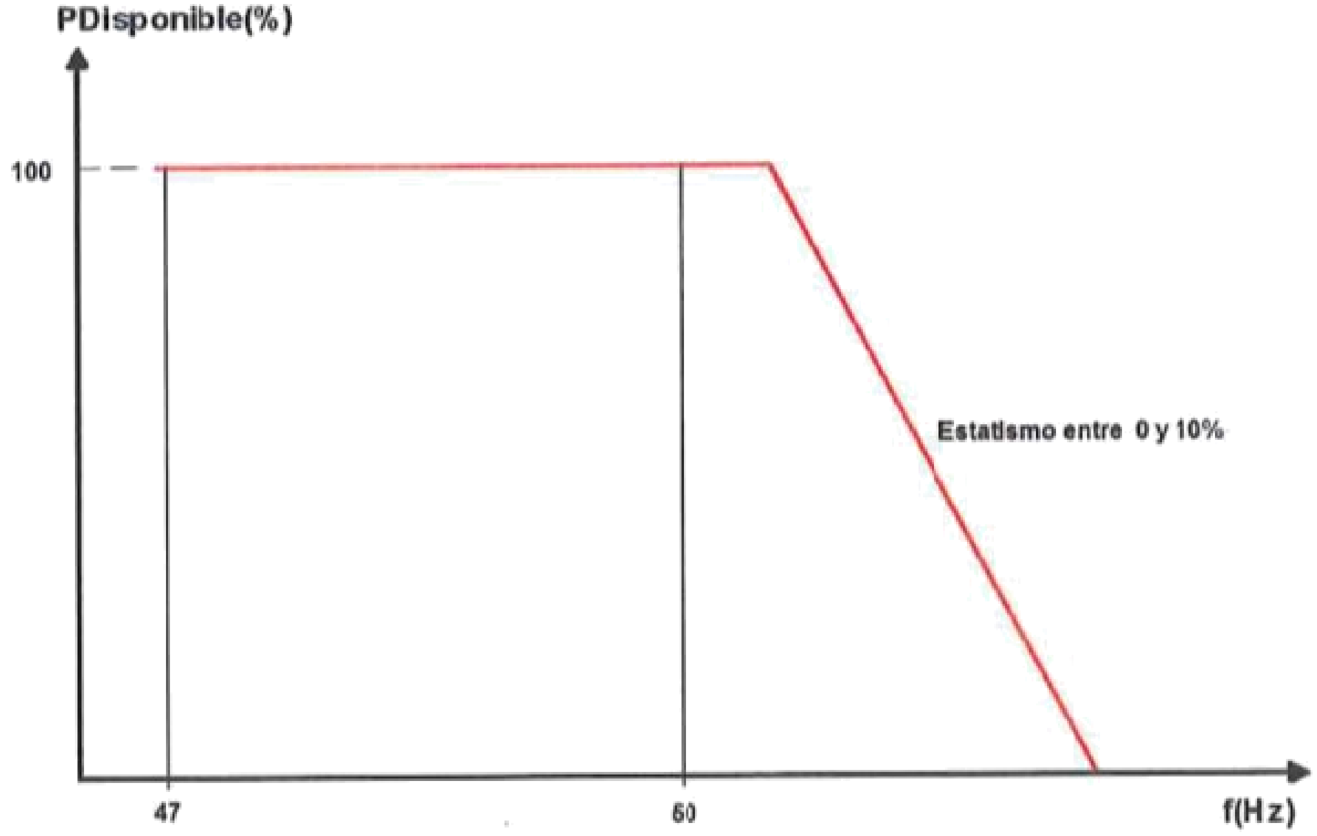
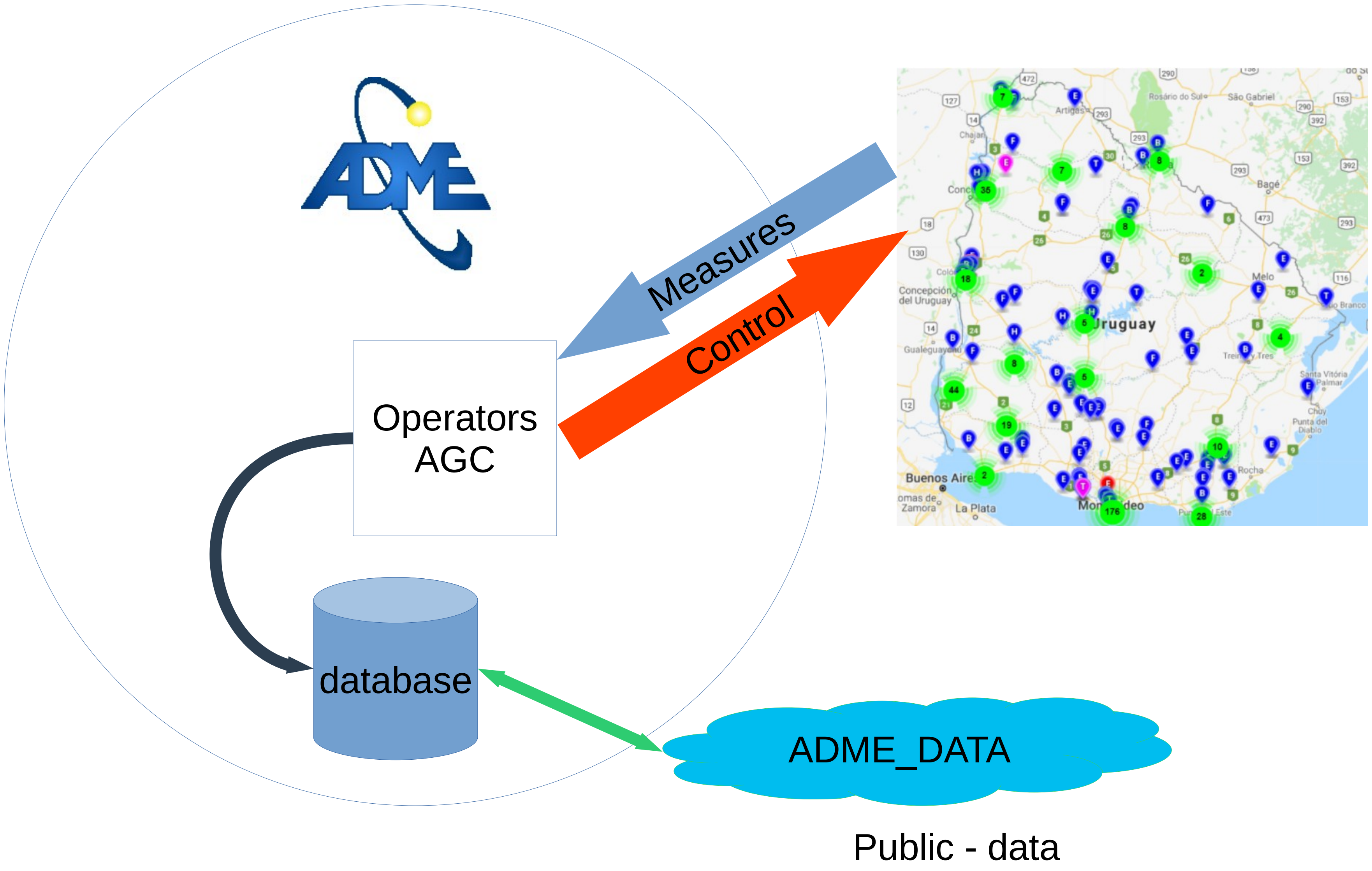


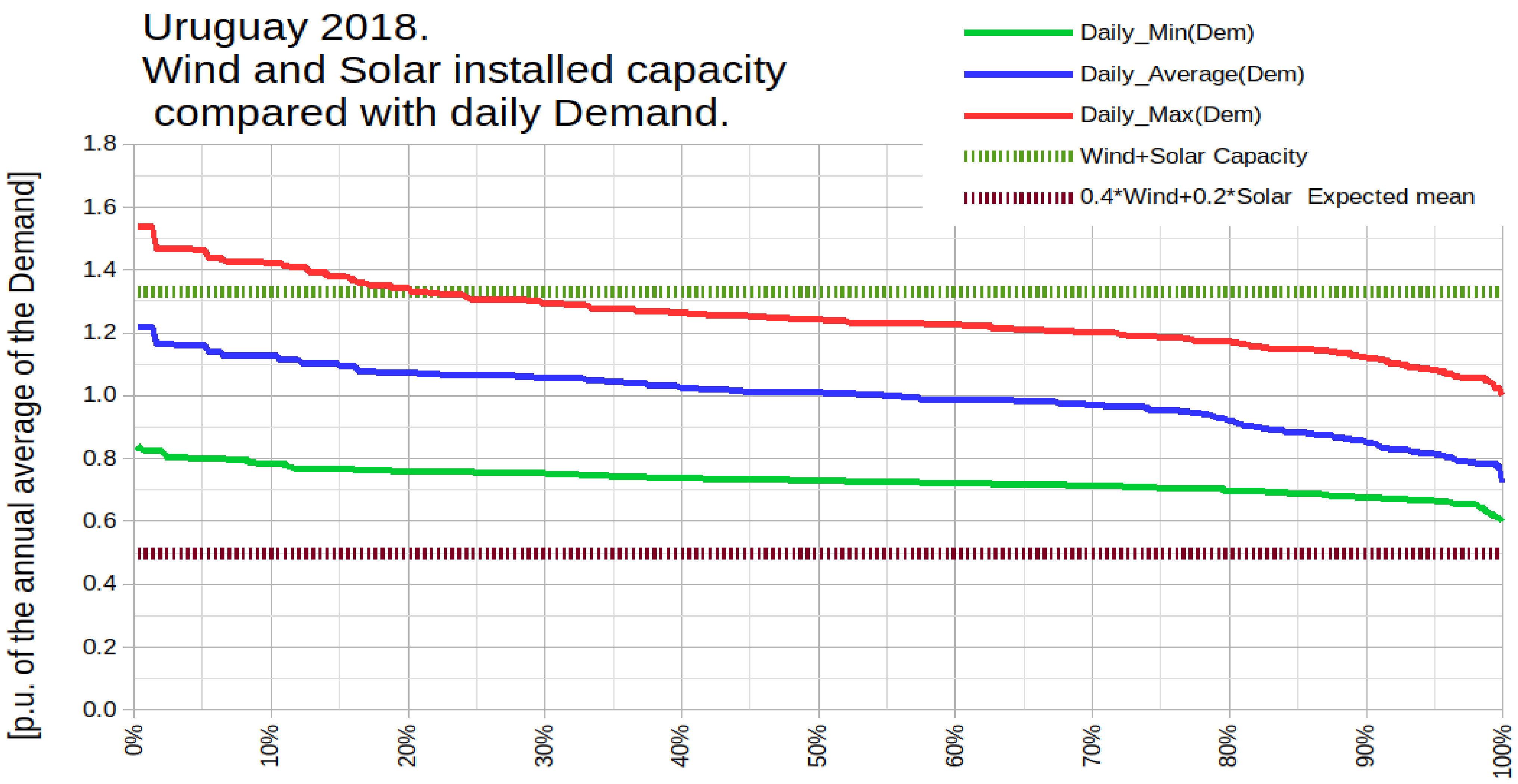
Figura 2

Wind and Solar power generation control.

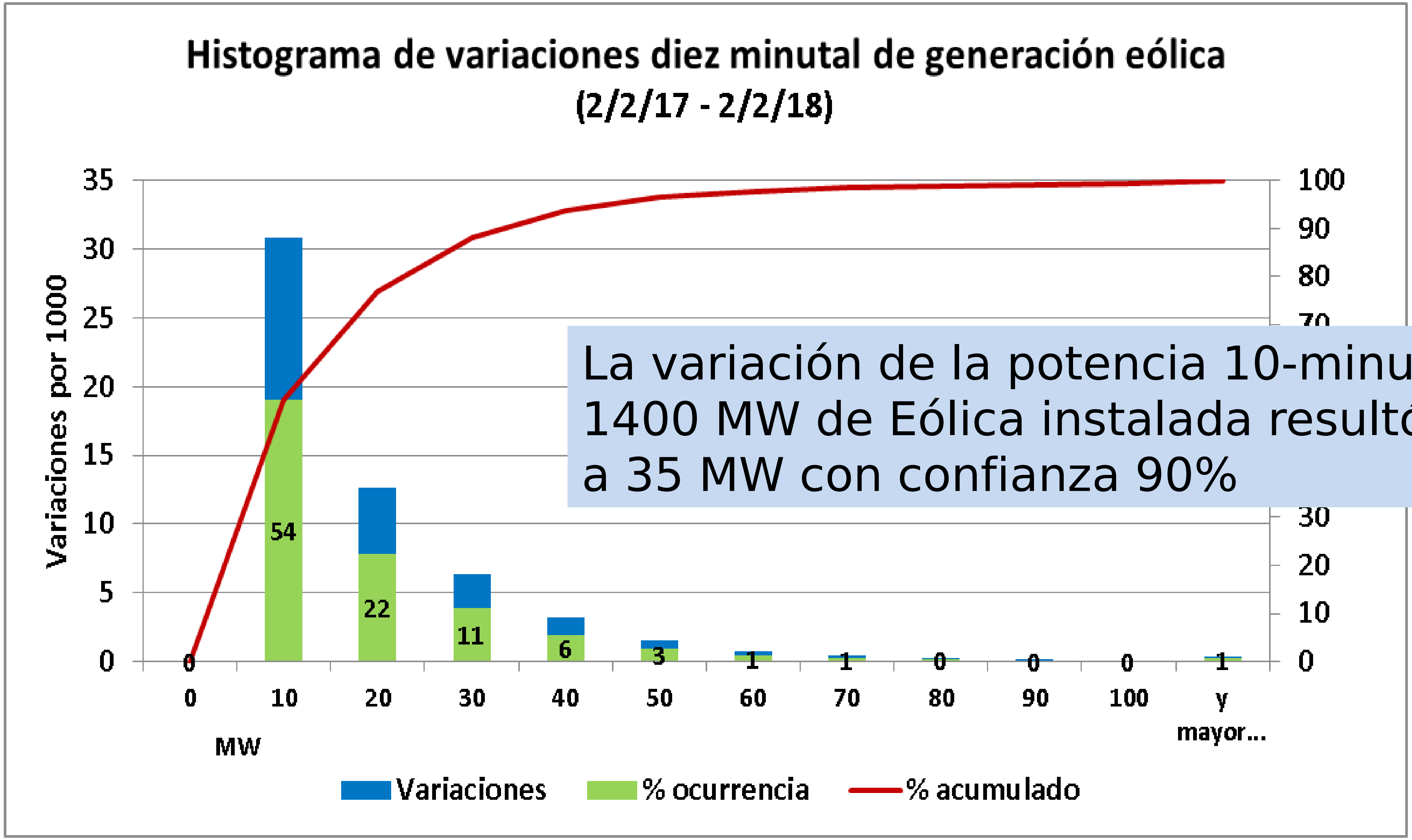
Maximum Generation Setpoint

Operational Restrictions or Curtailments



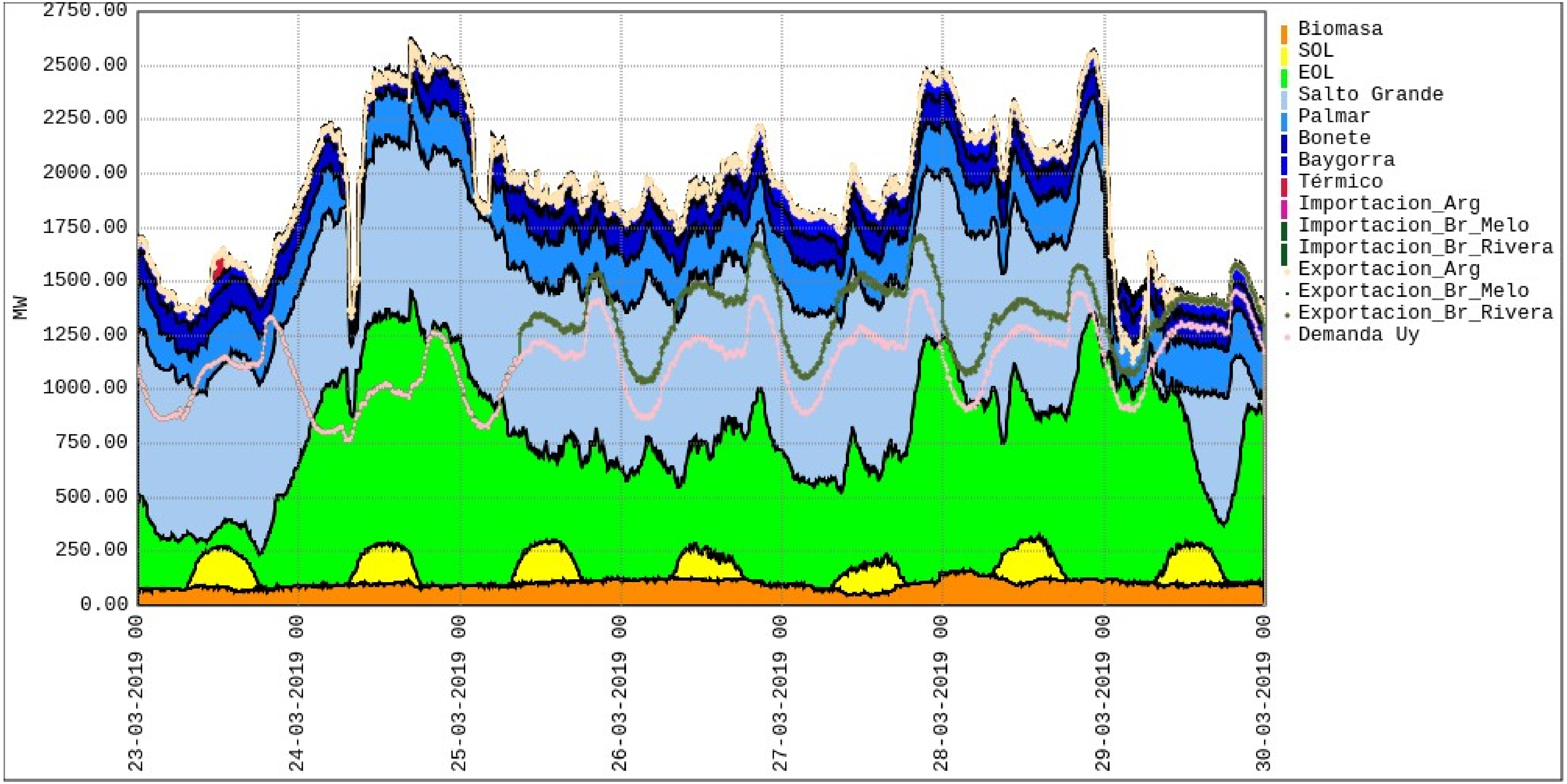


Uruguay 2018.
Wind and Solar installed capacity
compared with daily Demand.
Daily_Min(Dem)
Daily_Average(Dem)
Daily_Max(Dem)
Wind+Solar Capacity
0.4*Wind+0.2*Solar Expected mean
[p.u. of the annual average of the Demand]
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
0%
10%
20%
30%
40%
50%
60%
70%
80%
90%
100%

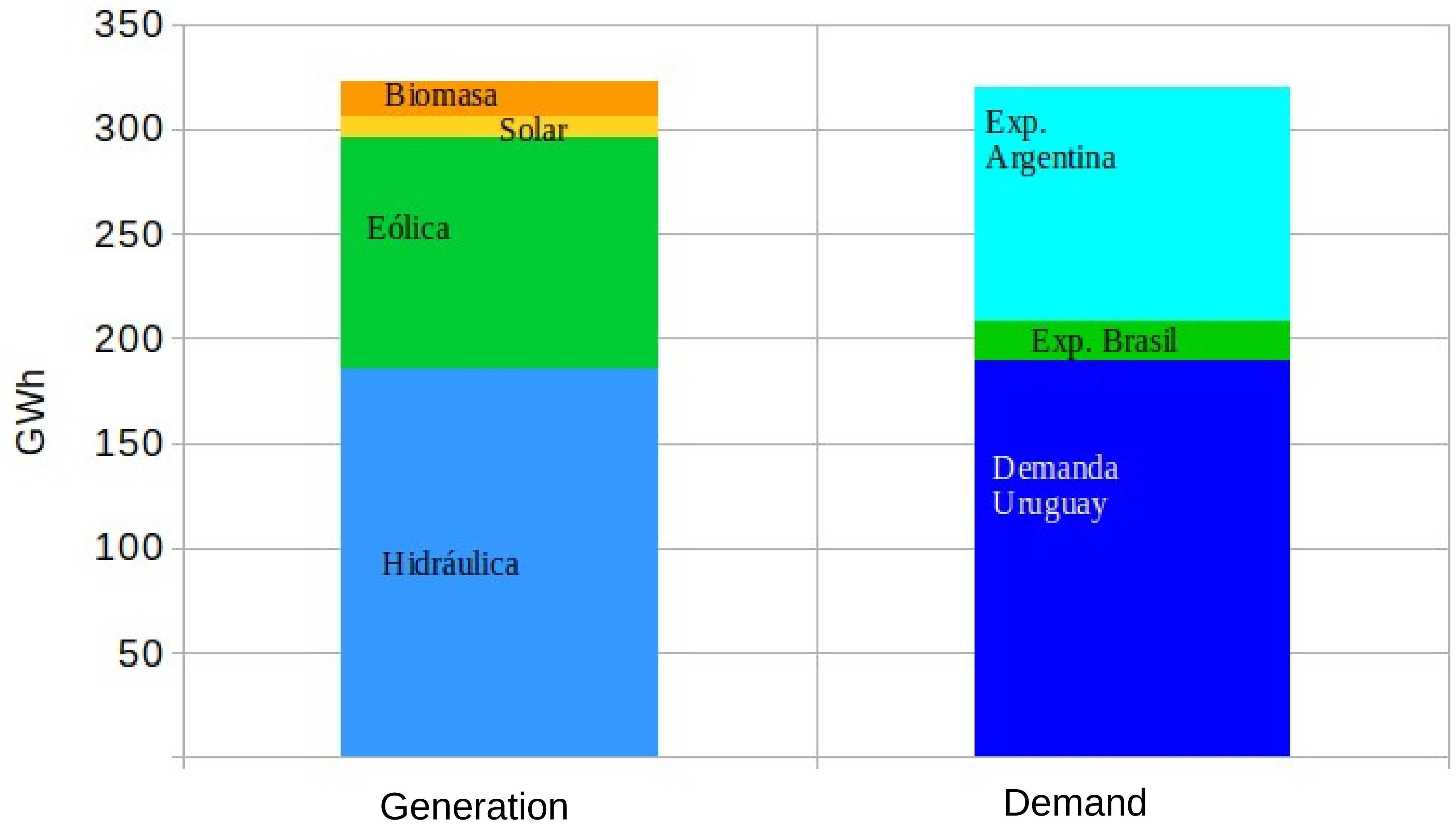


La variación de la potencia 10-minutal de 1400 MW de Eólica instalada resultó menor a 35 MW con confianza 90%

A week of March 2019 as an example of exported surpluses.



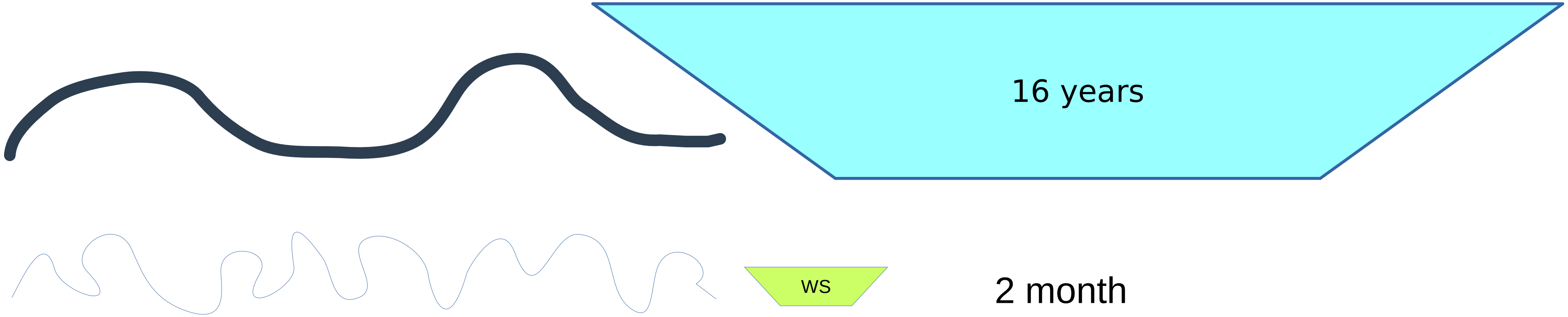
A week of March 2019 as an example of exported surpluses.



Characterization of the variability in Uruguay.

water inflows

wind & solar



averaging time to get the expected value with a tolerance of 10% and 90% confidence as a measure of filtering effort.

The wind does not change throughout the country simultaneously

- The variations of the total generation in 10 minutes are of the order of the variations of the Demand itself and are controlled with the demand tracking.
- Variations between hours may be more important, but are within the time limits that an Automatic Generation Control (AGC) and operators can manage without problems.

The main challenge is to be able to anticipate the power requirements of the National Interconected System.

- It is therefore essential to have tools that allow the simulation of the future optimal operation with hourly detail, considering FORECASTS and future UNCERTAINTIES..

The tools.

1) **SimSEE.** Optimal operation simulation platform with hourly detail and powerful stochastic models of renewable resources.
2) **OddFace.** Investment Optimizer.
3) **PRONOS.** Generator of forecasts of hydraulic contributions, wind and solar generation, temperature and demand.
   (https://pronos.adme.com.uy)
4) **VATES.** Application that runs continuously calculating the probabilistic dispatch, with hourly detail of the following 168 hours. It updates the information every hour and publishes it on the web.
   (https://vates.adme.com.uy)

Time-Step used for simulation.

Big time step / implicit inertia

balance restrictions
overestimate filtering capacity

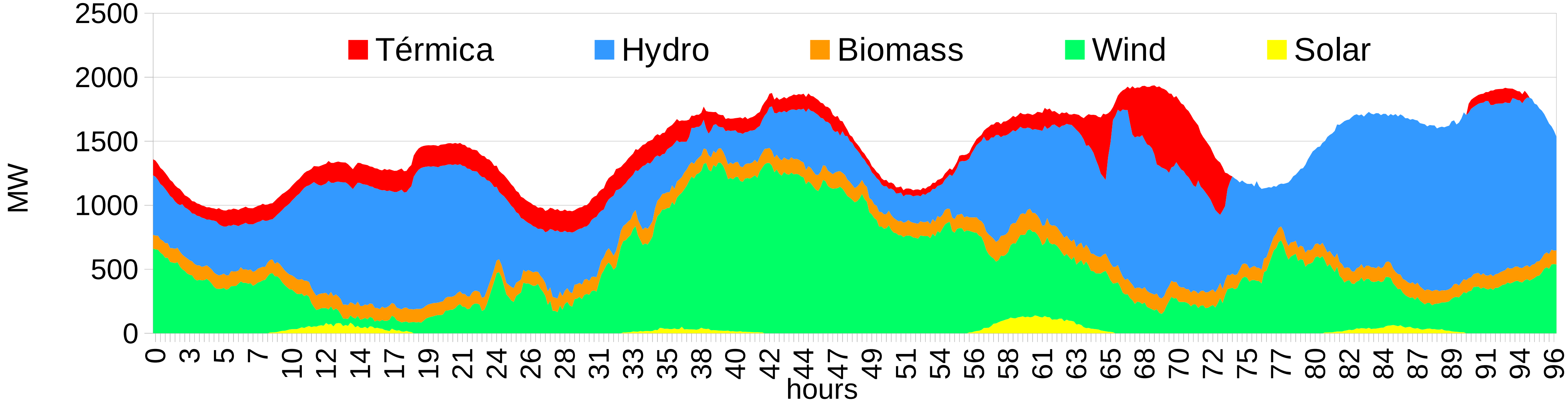
need of availability models to
represent
fail/repair inertia

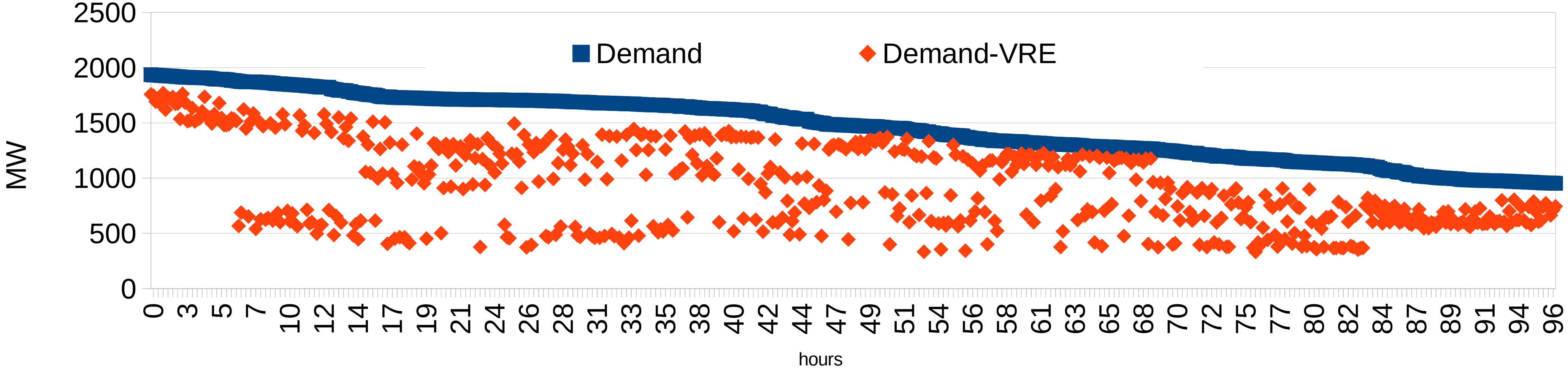
Small time step / more state variables

Time-Bands (Patamares) defined by the Monotonous Load Curve ...

Makes sense?

Only an example, 4 days of july-2018-Uruguay





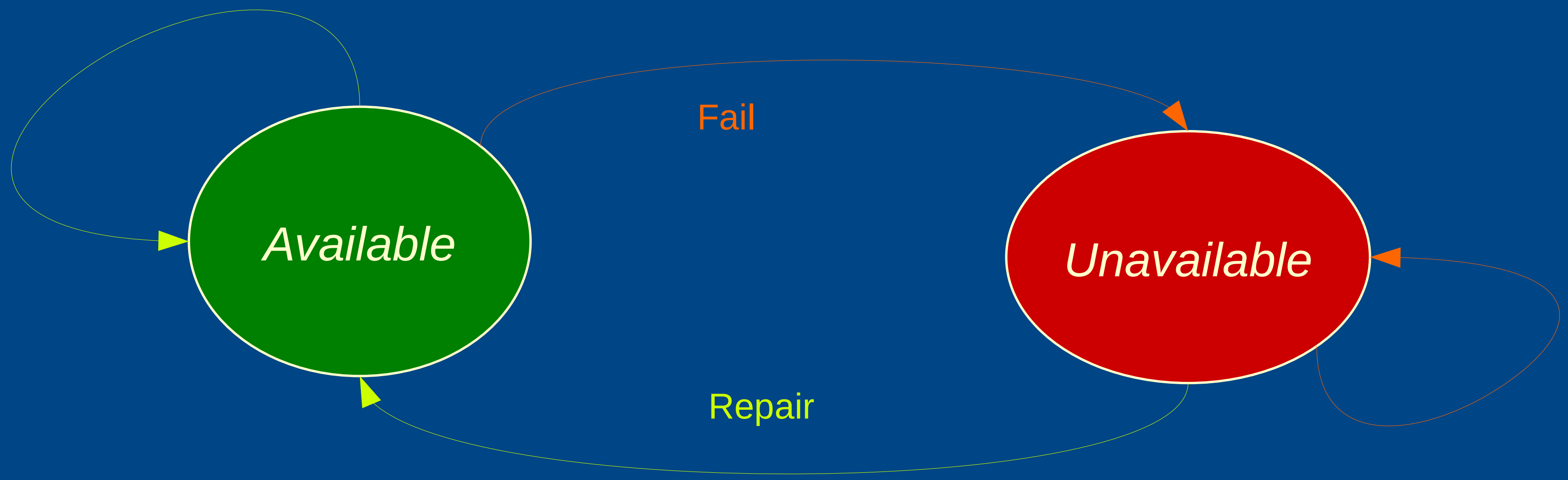
Source: ADME - SCADA ten-minute time series

Representación de la incertidumbre.

Fuentes
de aleatoriedad

- Demanda eléctrica.
- Caudales de aportes hídricos.
- Velocidad del viento.
- Radiación solar.
- Precio de los mercados regionales.
- Precios de los combustibles.
- Disponibilidad de combustibles.
- Roturas fortuitas

Availability of generators, power transmission lines, etc.

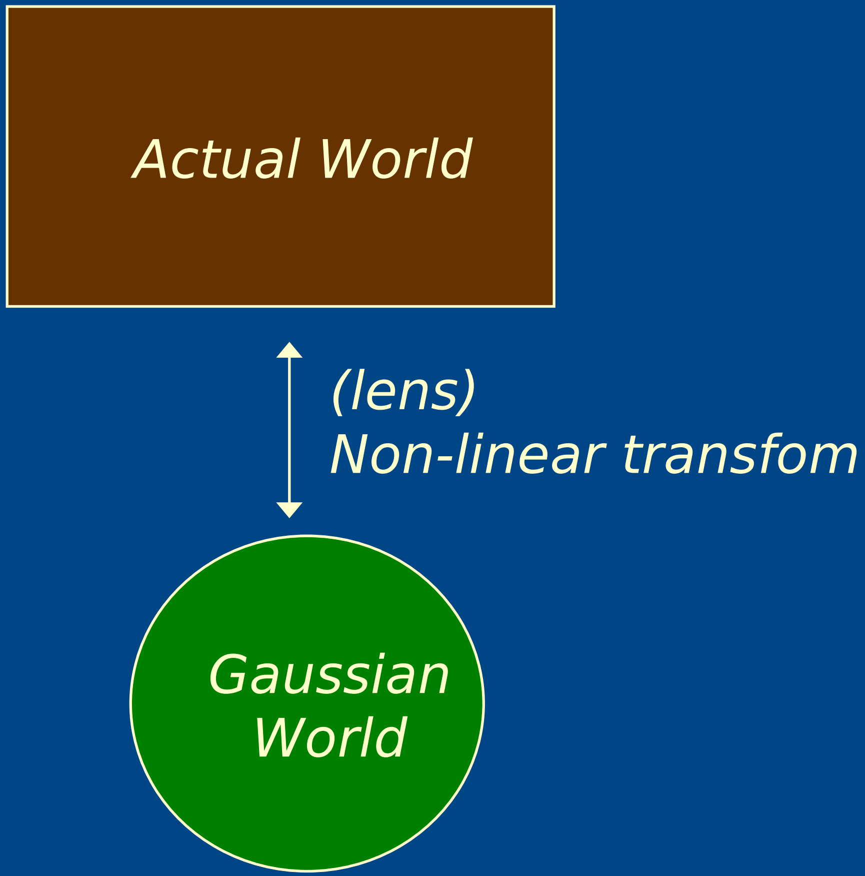


If we do not represent the state of the availability when simulating with small time-steps, the consequences of the inertia of the fault-repair process are underestimated.

Each generator, transmission line, etc. adds a Boolean state variable to the system.

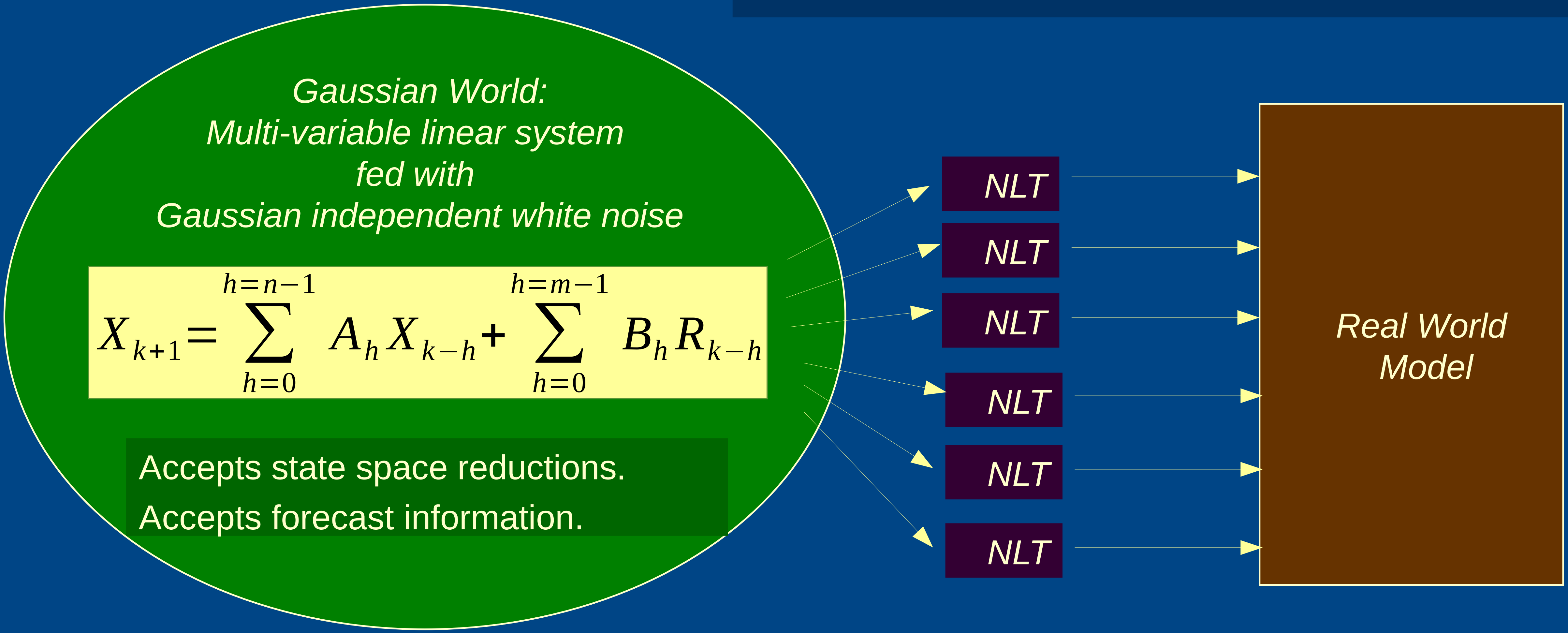
CEGH Modeling

- Keeps histograms of amplitudes.
- Keeps correlations.



CEGH modeling.

- reproduces the amplitude histograms of the original processes.
- reproduces the spatial and temporal correlations in a gaussian space.

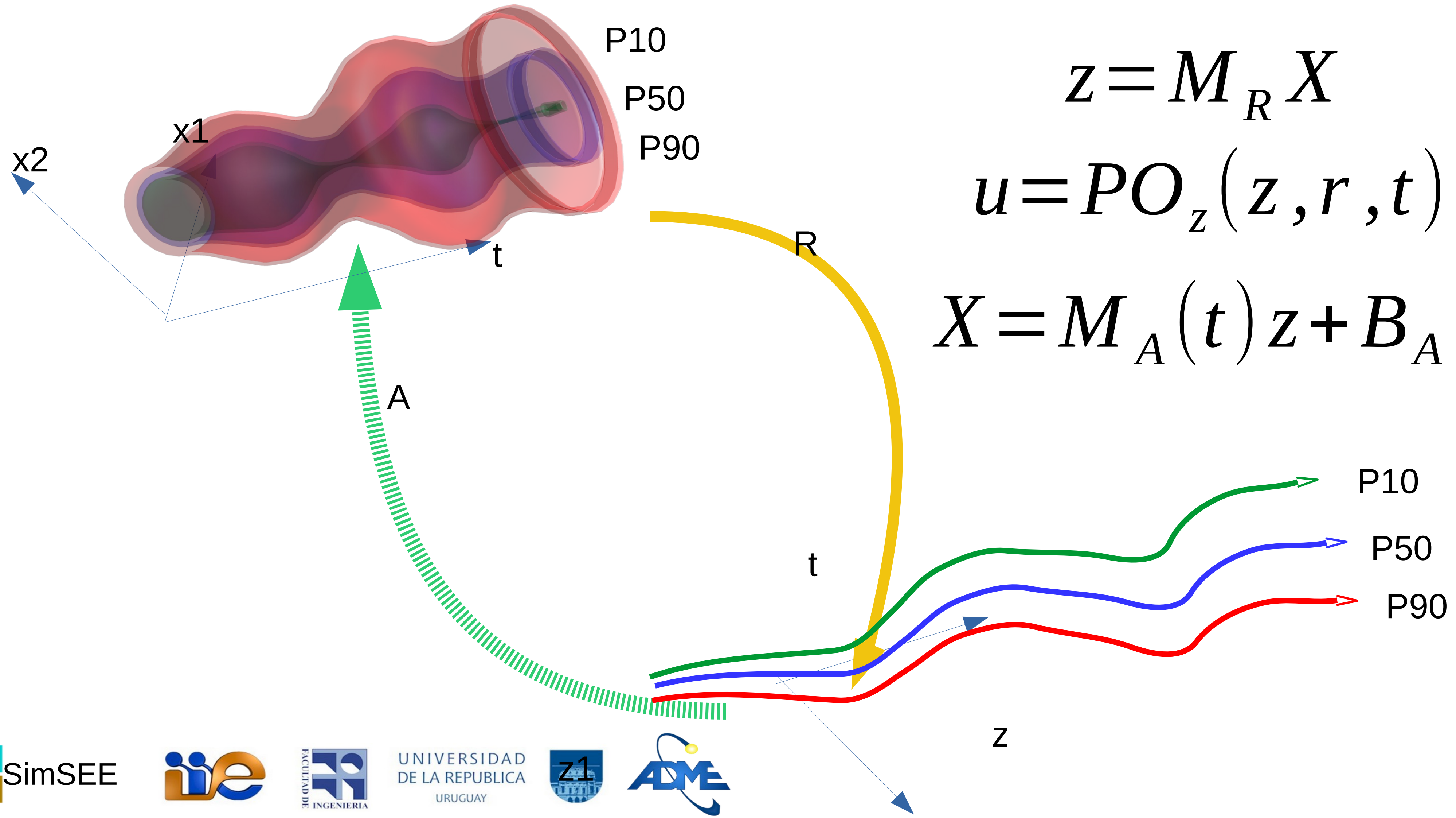


$$X_{k+1} = \sum_{h=0}^{h=n-1} A_h X_{k-h} + \sum_{h=0}^{h=m-1} B_h R_{k-h}$$

Bellman's curse of dimensionality.

CEGH

Treatment of forecasts in Gaussian space with reduction.



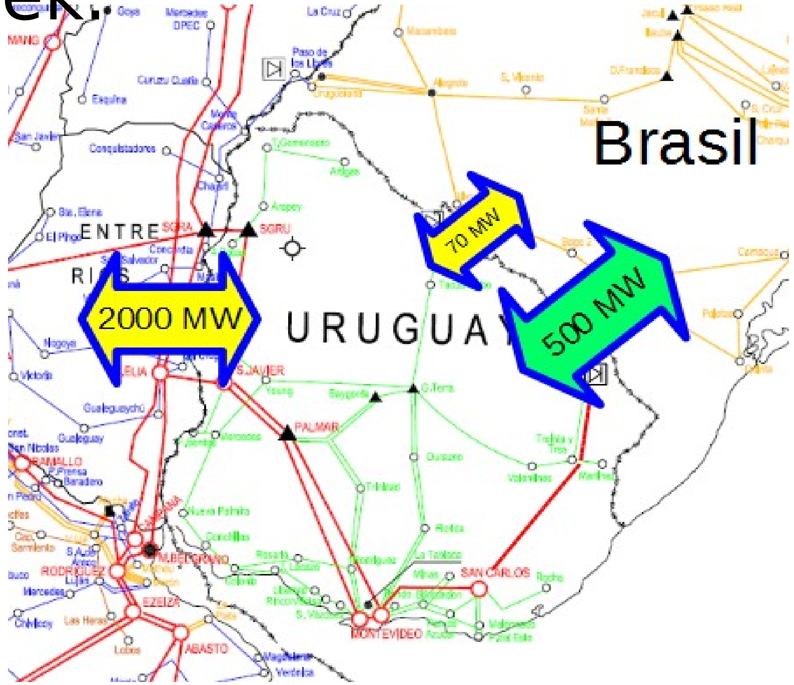
$$z = M_R X$$

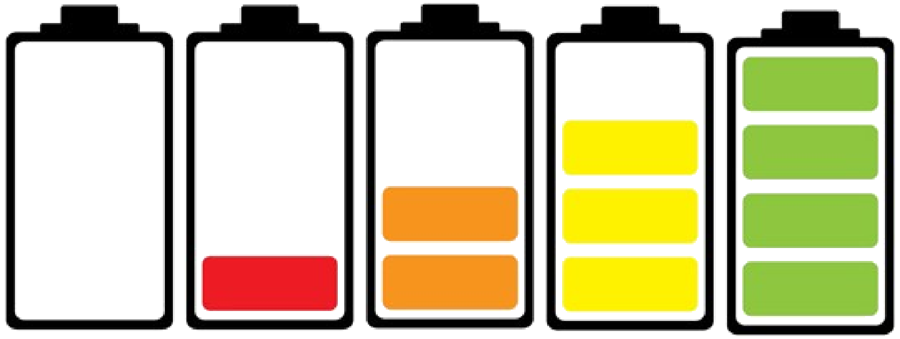
$$u = PO_z(z, r, t)$$

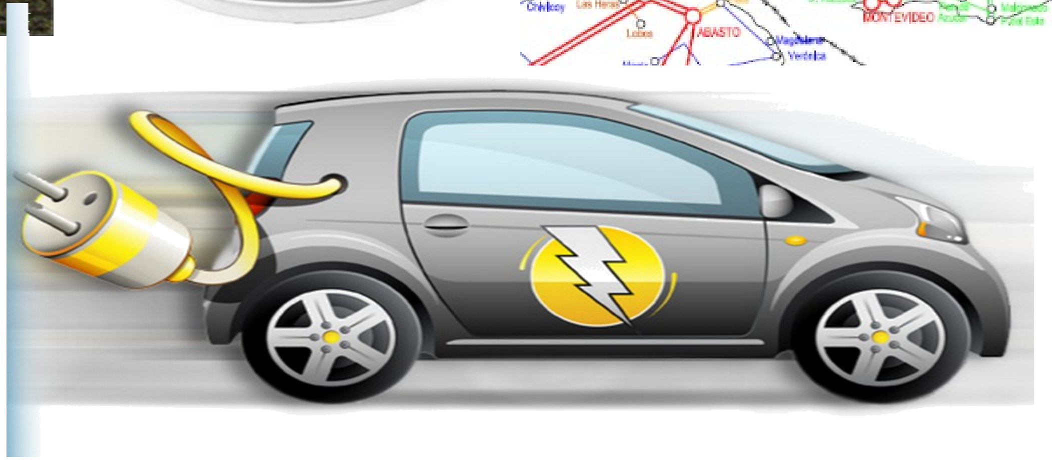
$$X = M_A(t) z + B_A(t) w$$

Optimize, optimize and optimize!

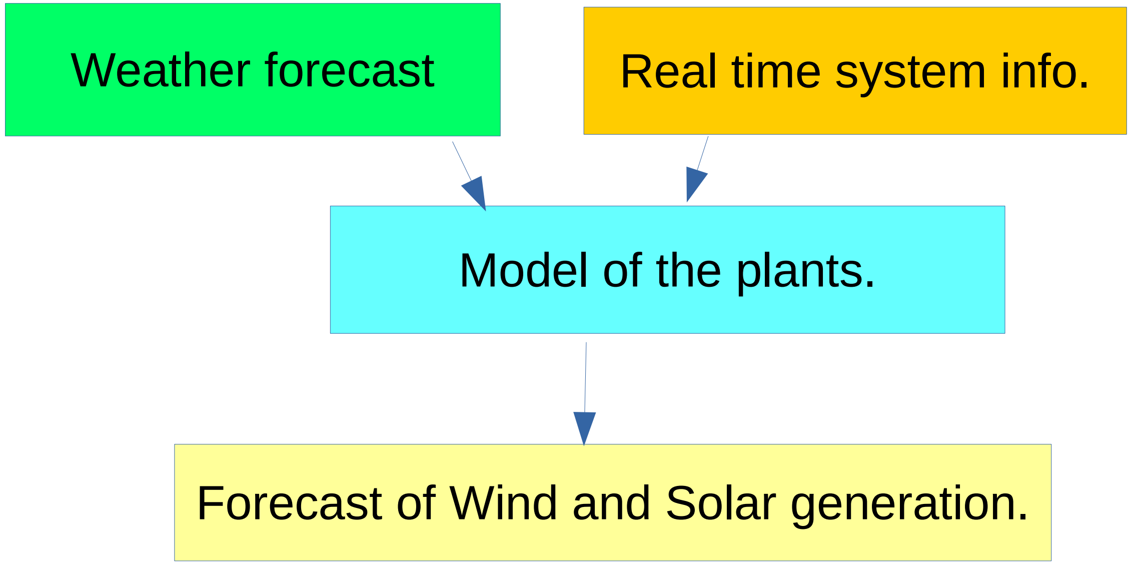
In the future, when the filtering capacity of the hydroelectric subsystem is exhausted, regional integration, Responsive Demands and Battery-storage will be the key to filter the variations of energy availability within the week.







PRONOS



https://pronos.adme.com.uy

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CAF BANCO DE DESARROLLO DE AMÉRICA LATINA
ADME
UTE La energía que nos une

Operador Sin Pronósticos.

Operador Con Pronósticos.

VATES

Forecast of the next 168 hours of the power system operation.

https://vates.adme.com.uy

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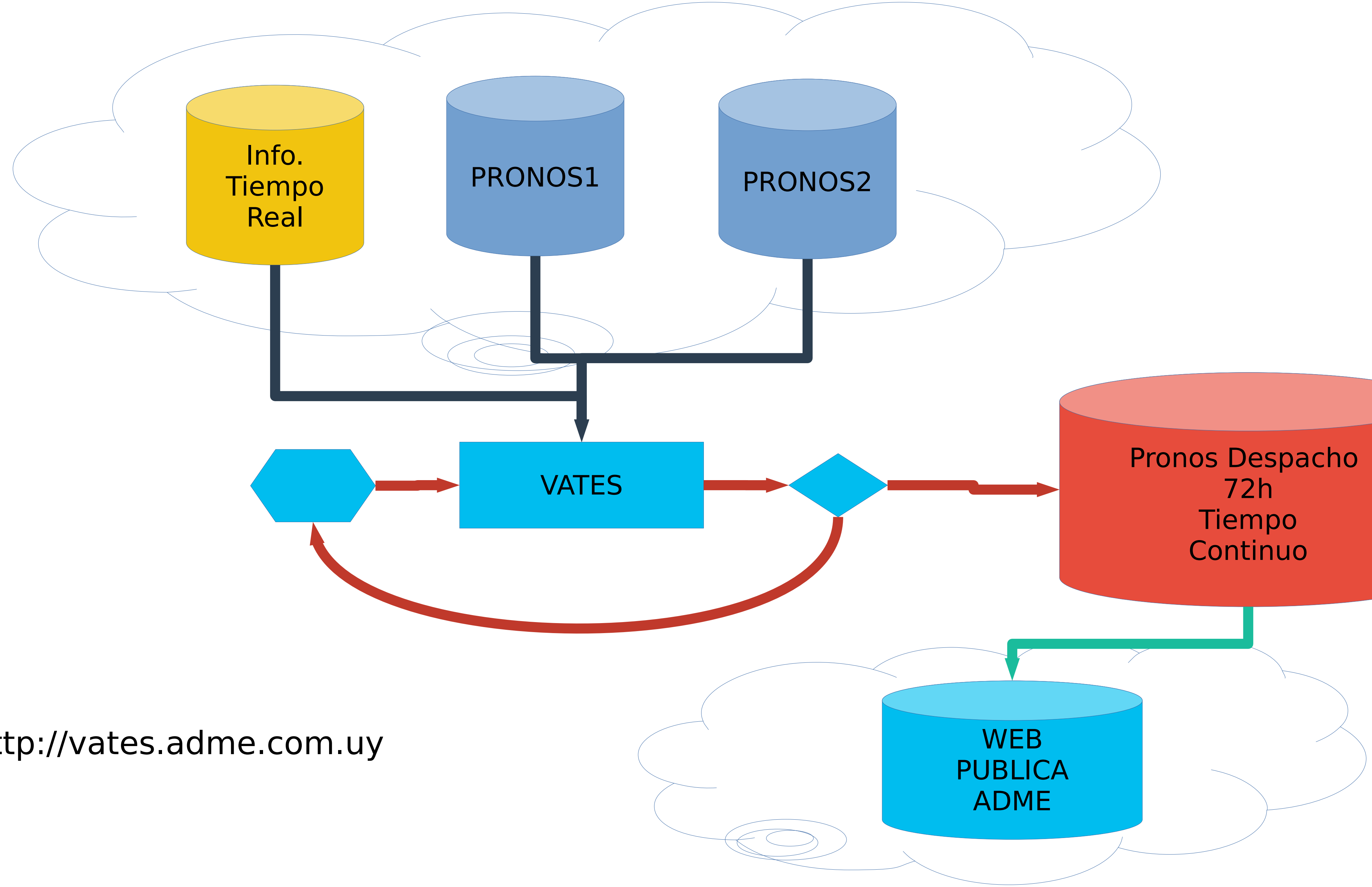
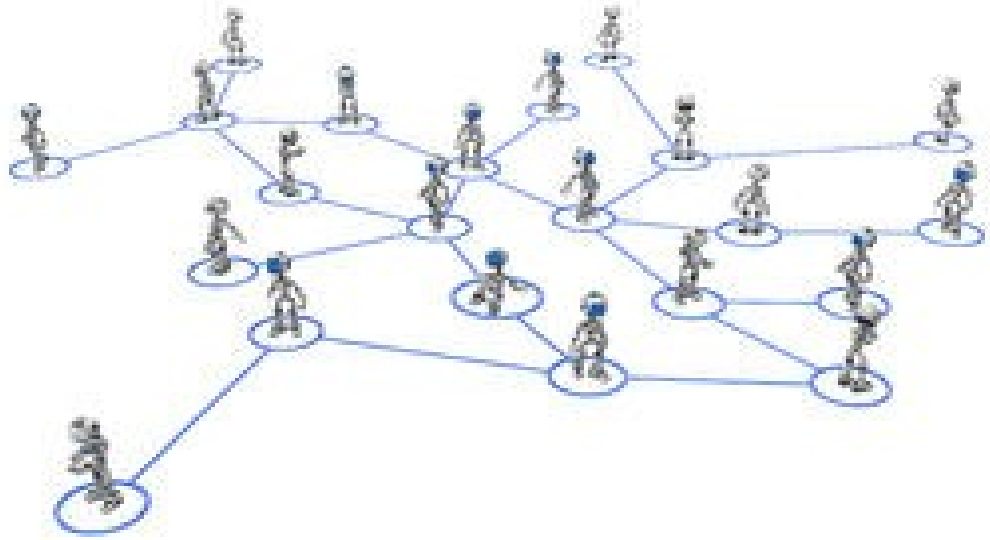


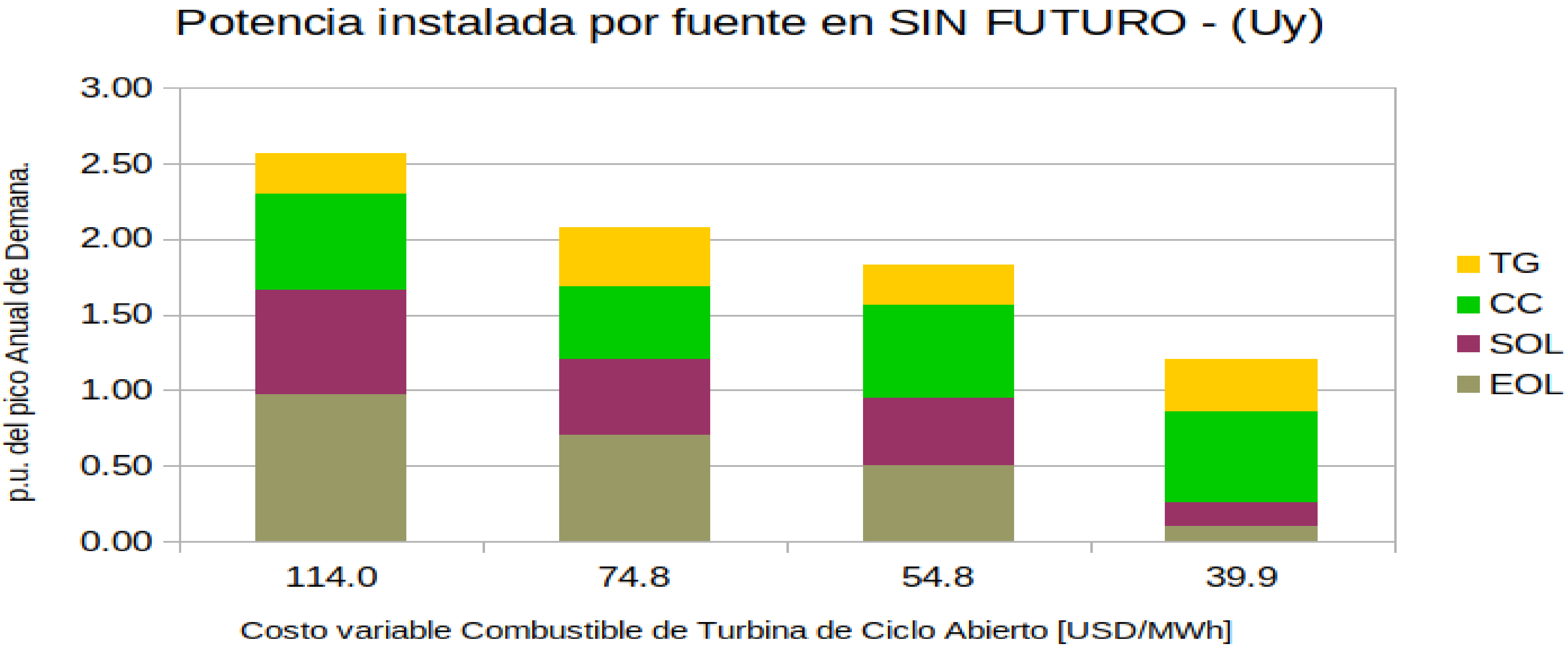
http://vates.adme.com.uy

OddFace

Optimization of the investment plan.



Evolución de los Mercados (TES).



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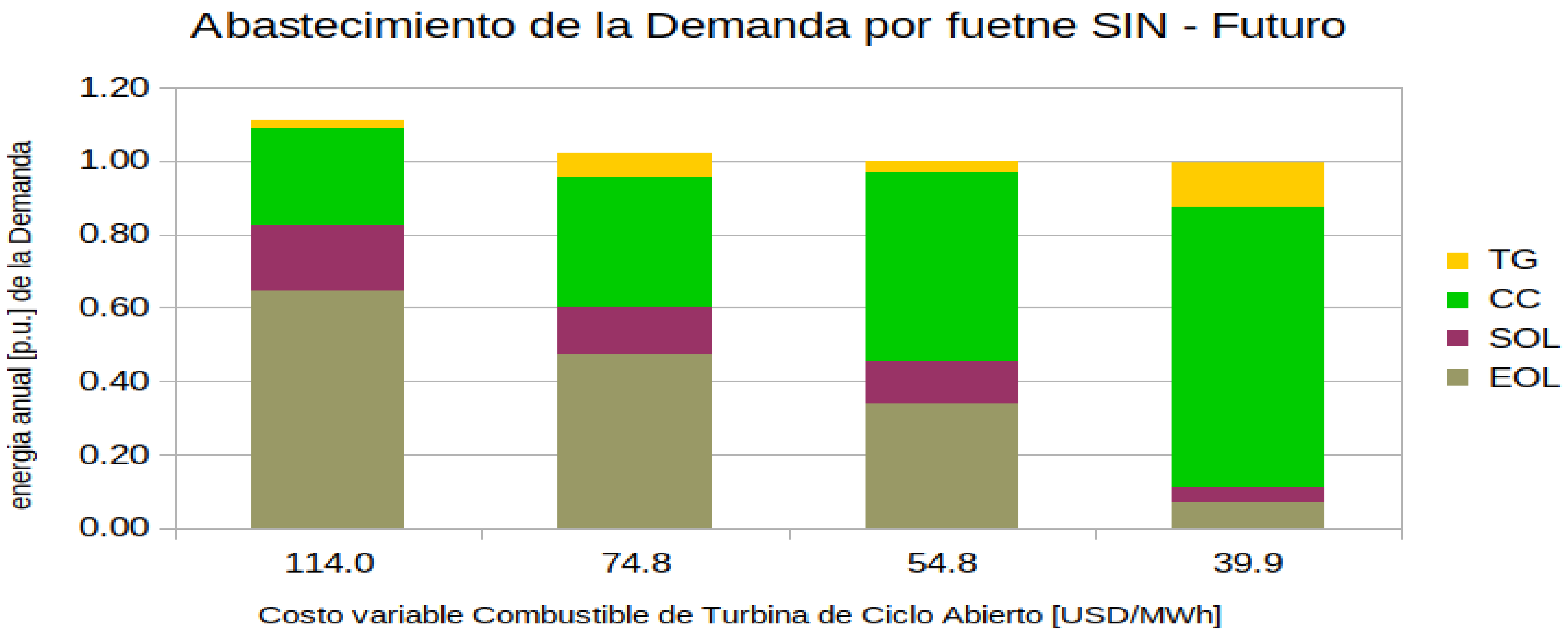
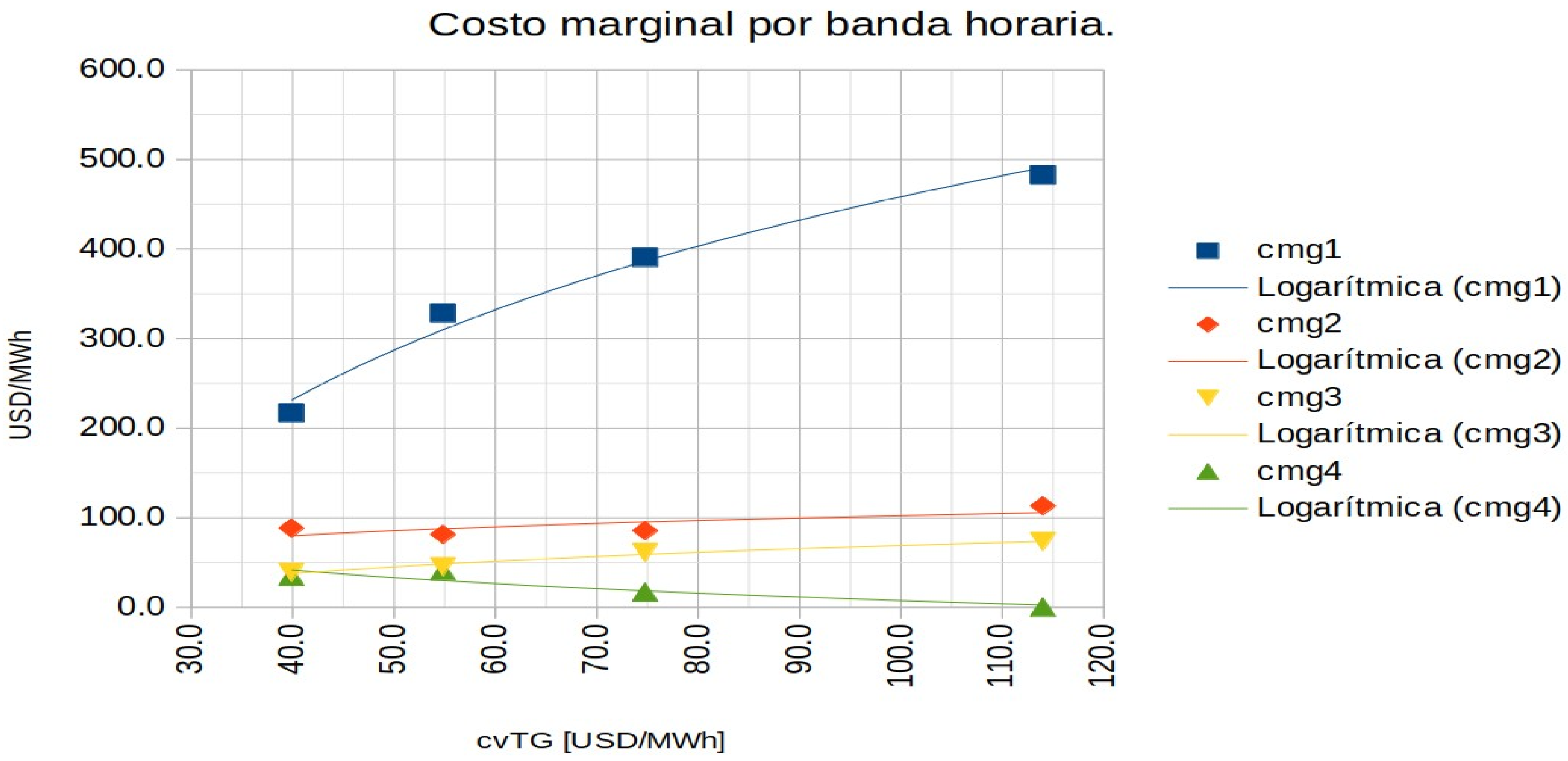


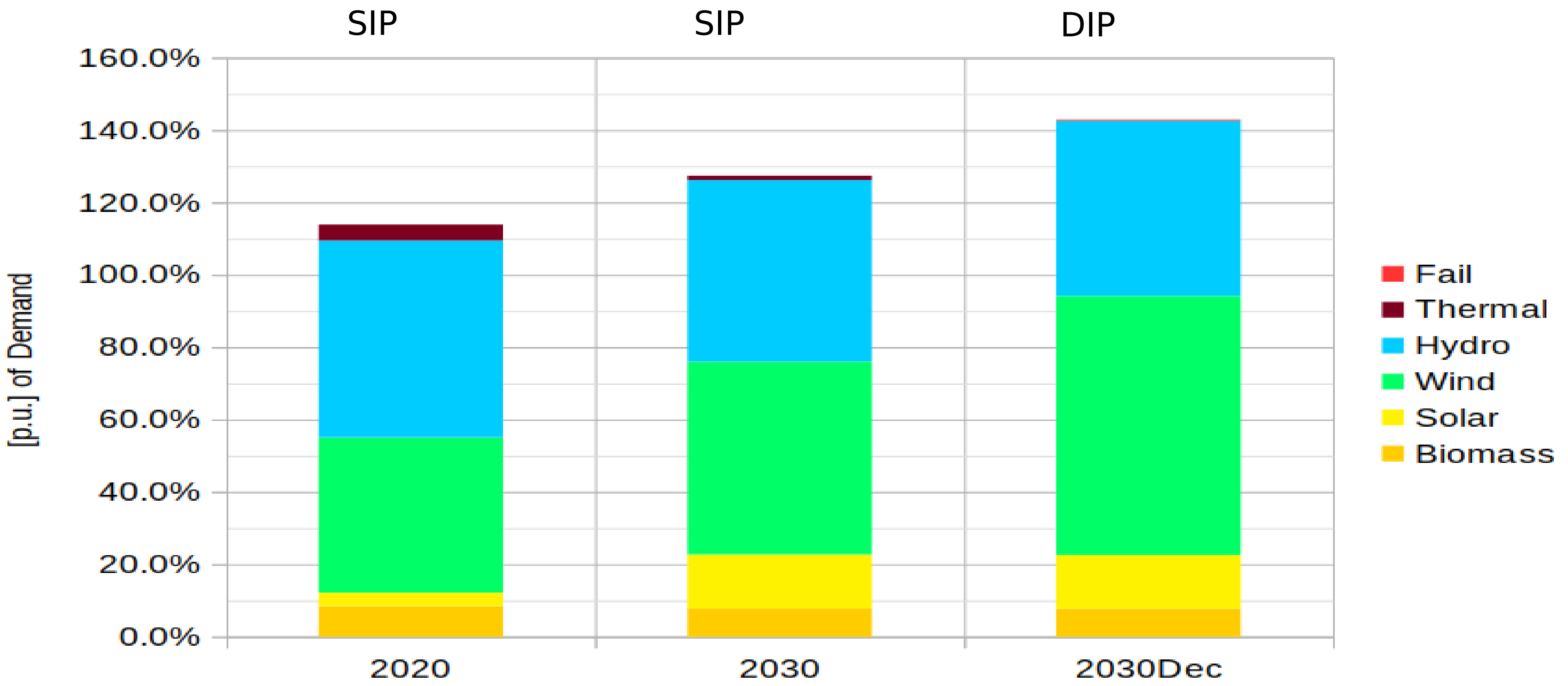
Sensibilidad a la opción térmica.



Evolución del CMG.

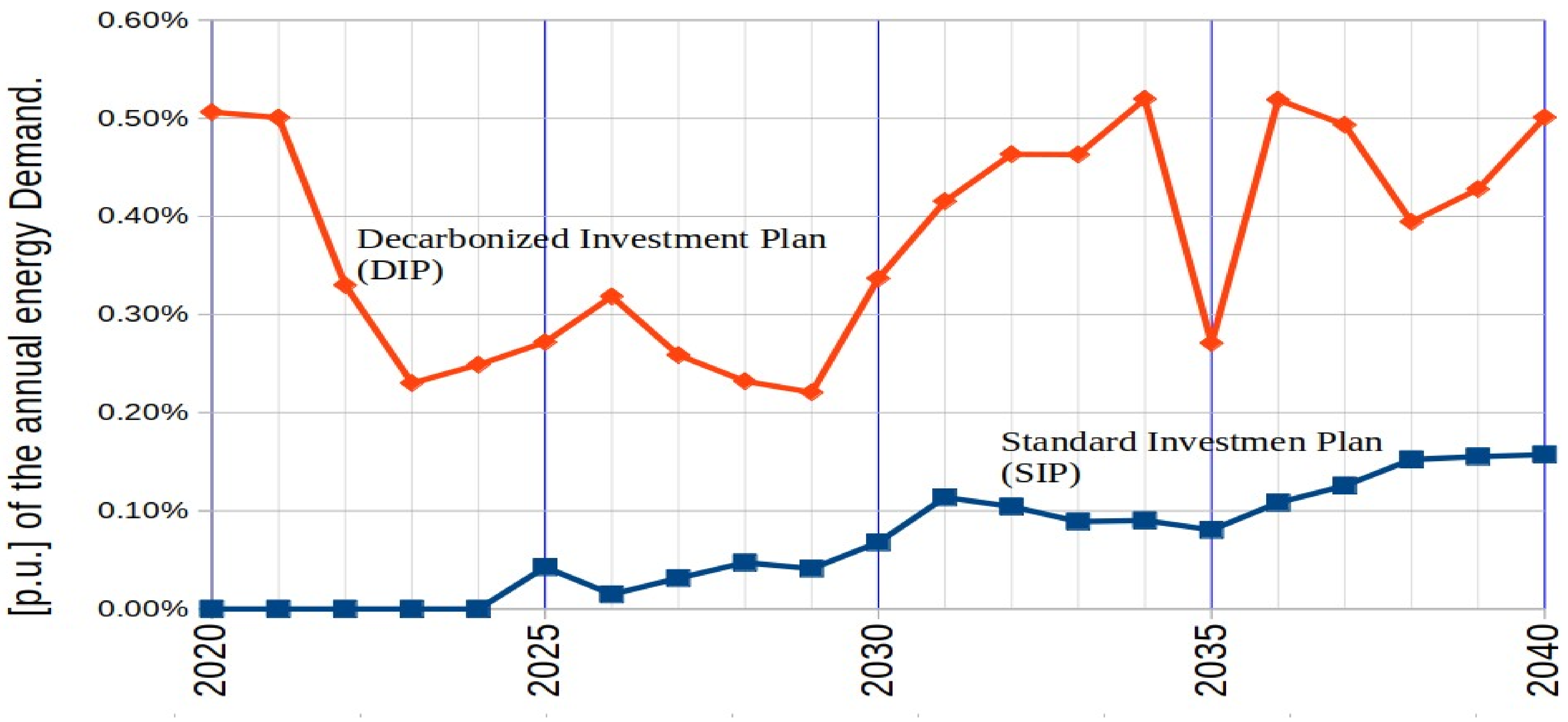
$$CGH_j = \left(\frac{Dem_{2019}}{Dem_j}\right) CGH_{Actual} + \left(1 - \frac{Dem_{2019}}{Dem_j}\right) CGH_{SINF}$$

Main results.

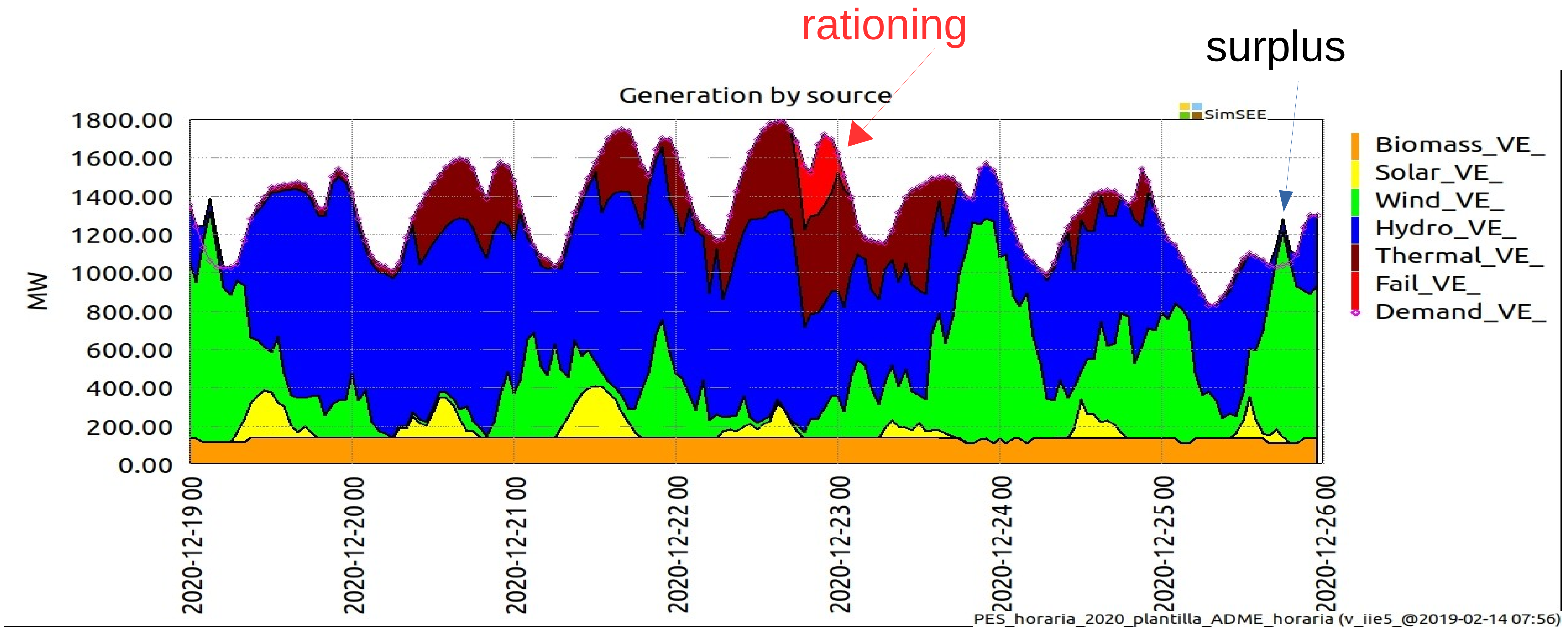


Case	**Biomass**	**Solar**	**Wind**	**Hydro**	**Thermal**	**Fail**	**Surplus**
2020	8.5%	3.6%	42.9%	54.4%	4.4%	0.06%	13.9%
2030	7.9%	14.9%	53.2%	50.3%	1.2%	0.04%	27.5%
2030Dec	7.7%	14.9%	71.5%	48.5%	0.0%	0.29%	42.9%

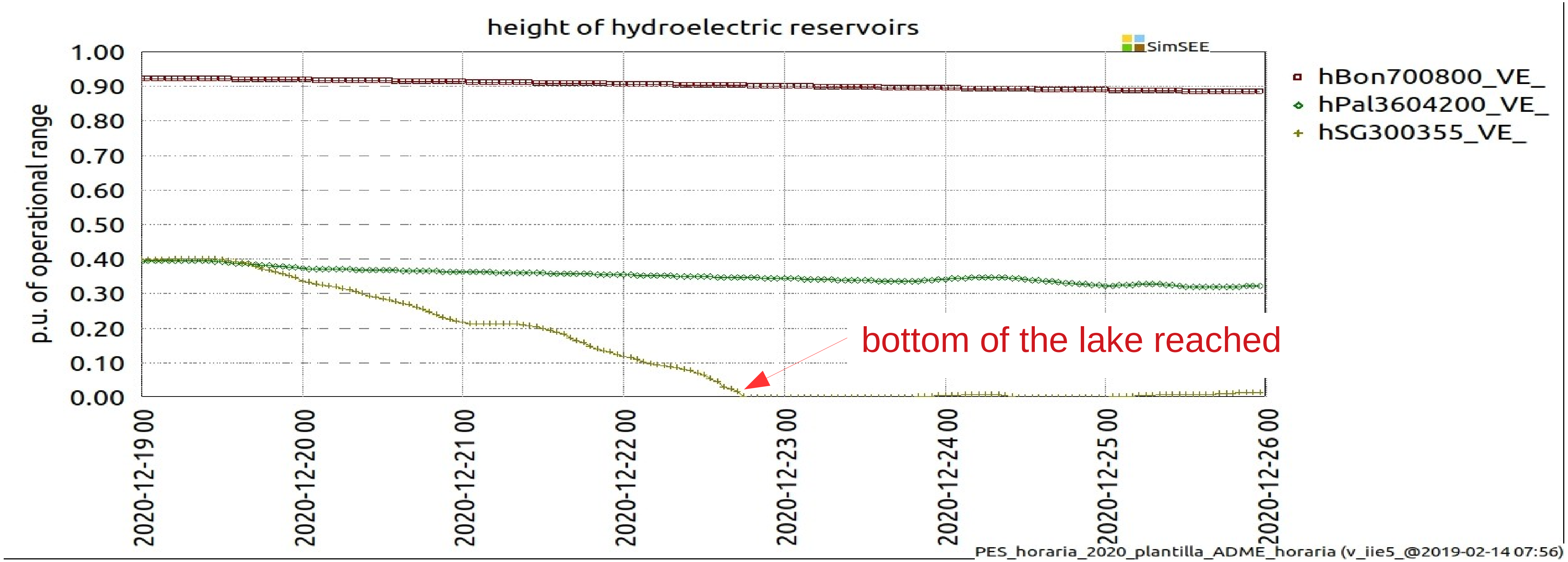
Annual energy failure PE(10).



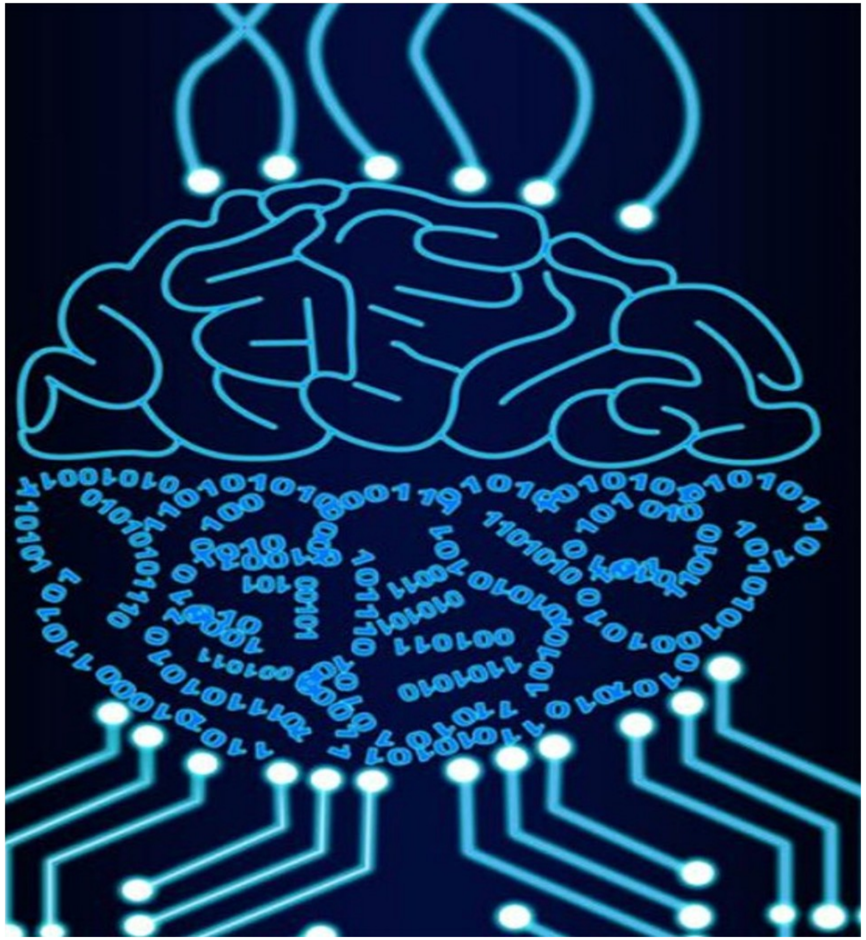
A realization with energy rationing and energy surplus.

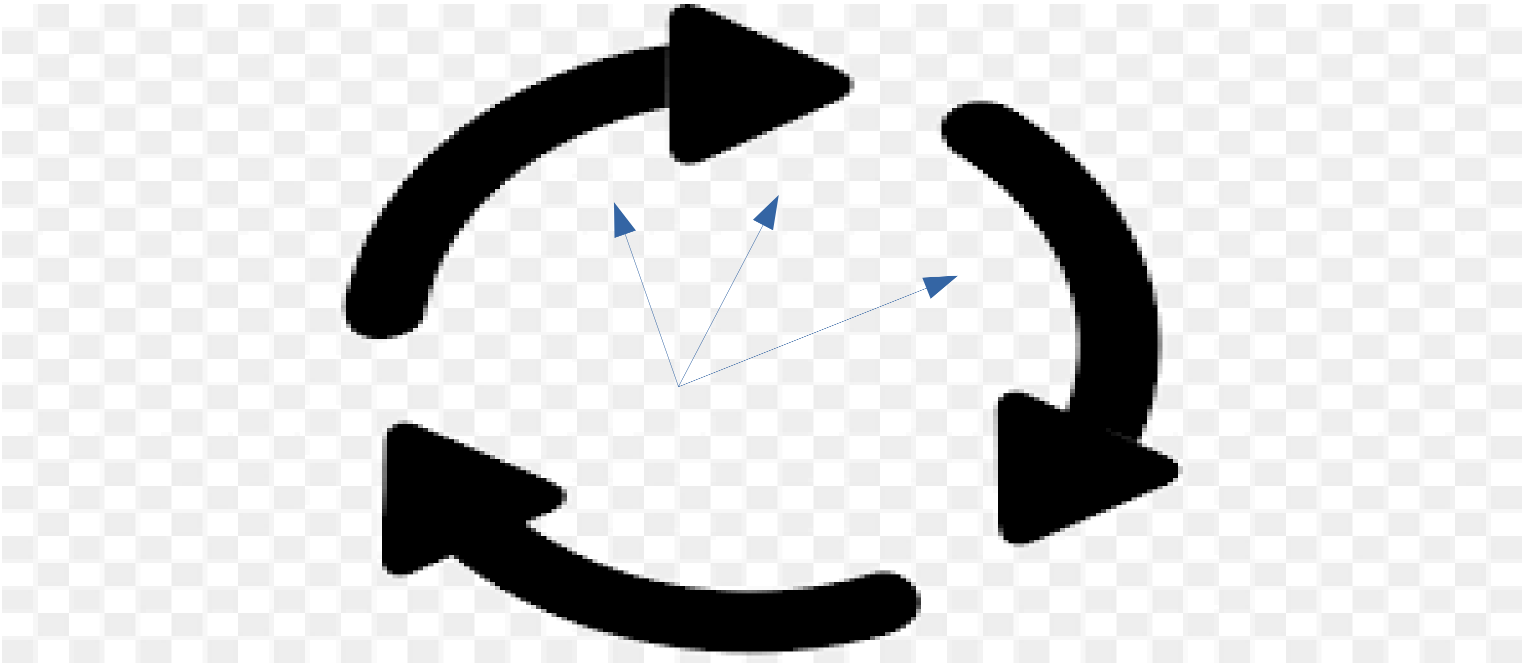


Evolution of the height of hydro-reservoires.



What we are working on now for the future.





Knowledge

Hard work

Creativity

Curiosity

Persistence

Thank you very much for your attention!

Be quick enough not to miss the train and slow enough not to get on the wrong one.