ENERGÍAS RENOVABLES
DESARROLLO SOSTENIBLE

14 al 16 de Noviembre
SALTO GRANDE

IEEE

salto grande
Argentina-Uruguay

Tutorial:
Utilización de SimSEE para la gestión óptima de los recursos de generación de Uruguay.

Julio 2016 - Montevideo - URUGUAY

FACULTAD DE INGENIERIA

UNIVERSIDAD DE LA REPUBLICA
URUGUAY

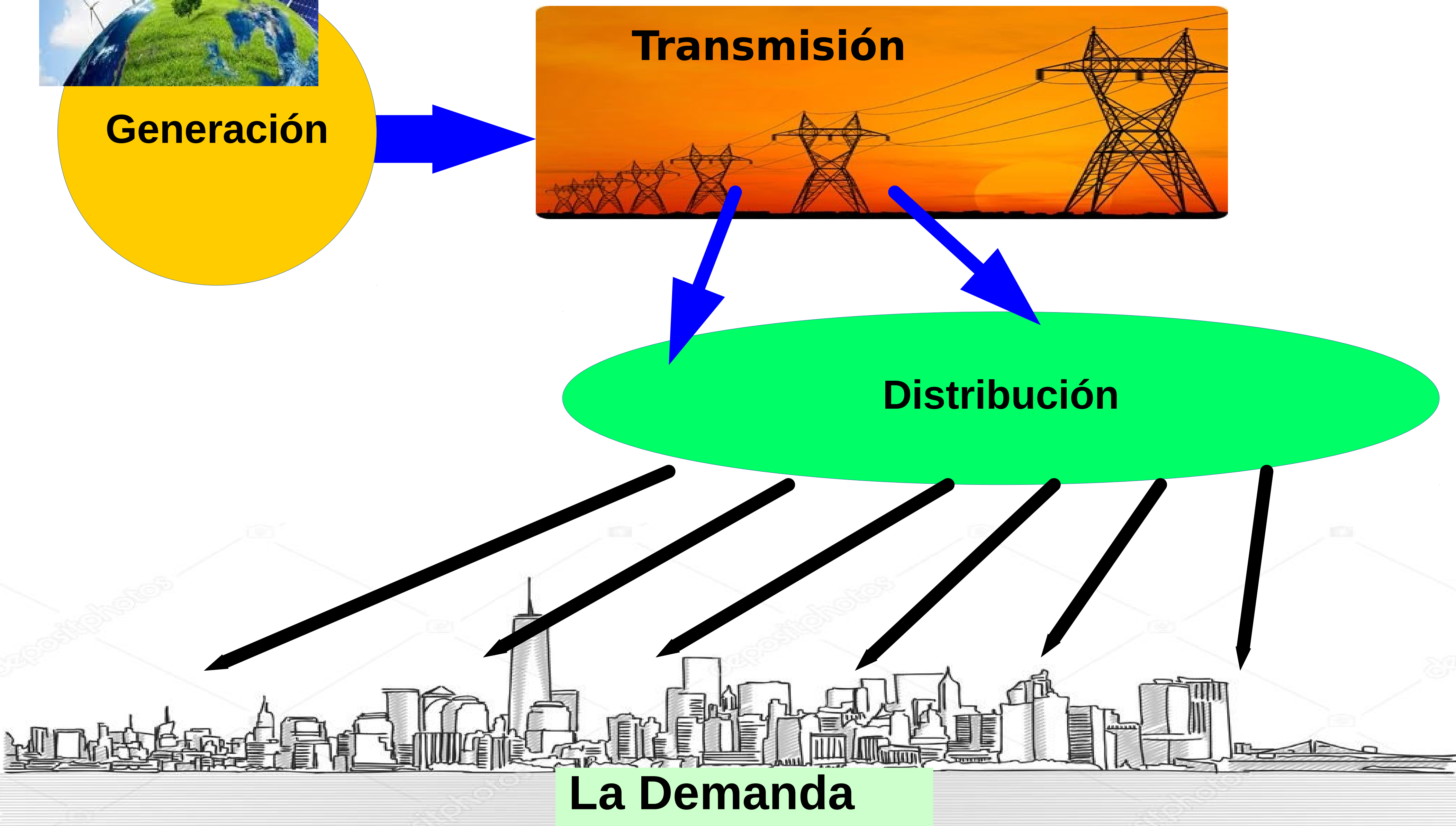
ADME

Ruben Chaer
Prof. Adjunto. IIE-FING-UdeLaR
Gerente T&DNC - ADME.
Senior Member - IEEE

Objetivo de operar un Sistema de Energía Eléctrica

*Suministrar **La Demanda** al menor costo posible en condiciones de calidad aceptable.*

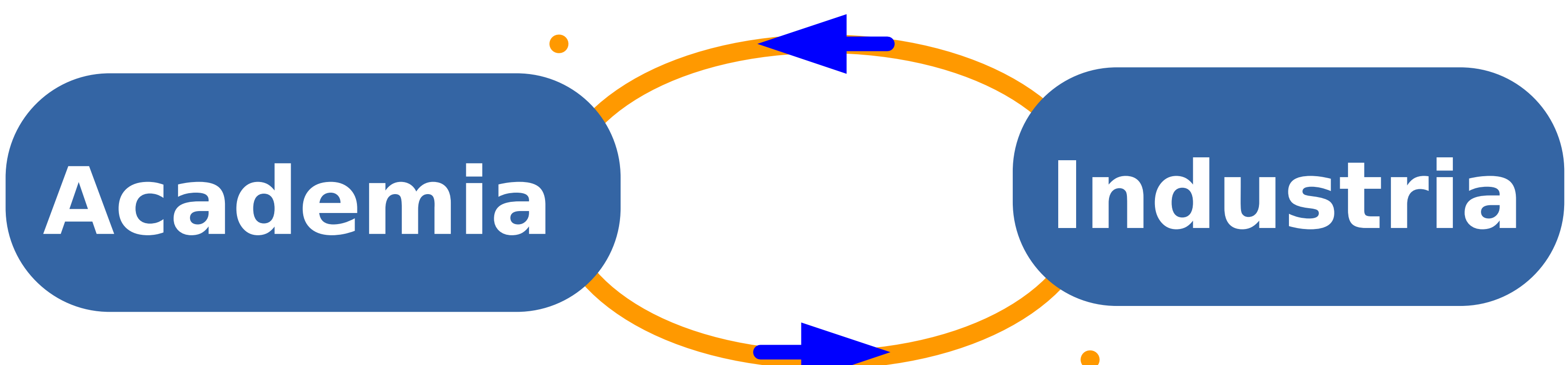
Estructura clásica del sector eléctrico.



SimSEE

PDT 47/12 BID – CONICYT 2006-2007
ANII-FSE 2009-128 Mejoras 2010-2011
ANII-FSE-1-2011-1-6552 Modelado Autoctonas 2012-2013
ANII-FSE_1_2013_1_10957 OptimA 2014-2015
ADME-CAF-FJR - Pronos 2016
ADME-FING Modelos Parques 2016-2017
ADME-FING VATES. 2016-2018
ANII-FSE_1_2017_1_144926 Var+Red+Gestión Dem. (en ejecución)

PDT
ANII AGENCIA NACIONAL DE INVESTIGACIÓN E INNOVACIÓN
CAF BANCO DE DESARROLLO DE AMÉRICA LATINA
ADME
UTE La energía que nos une

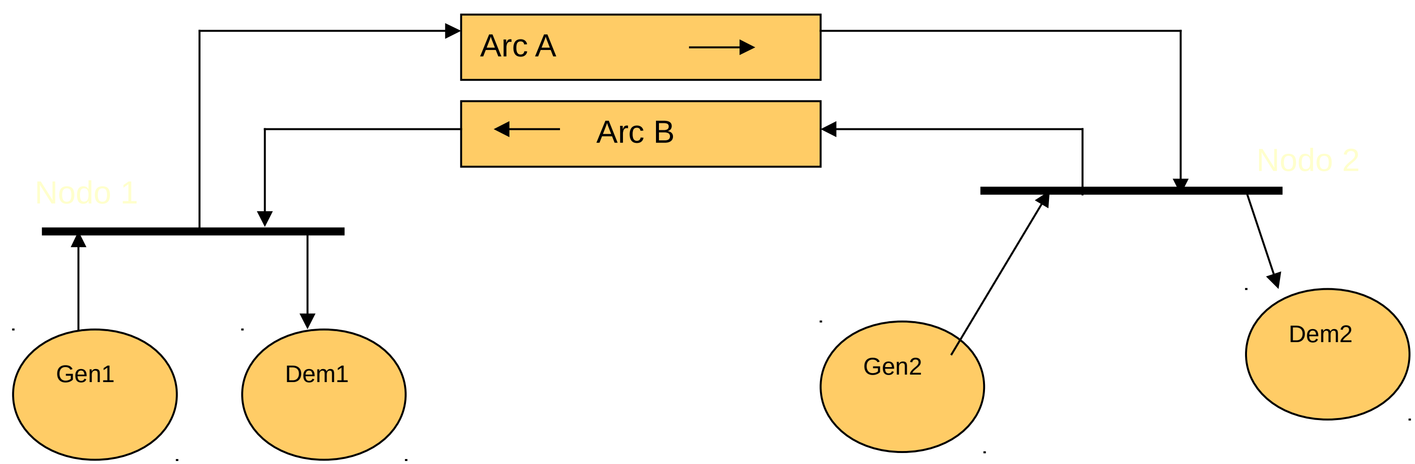


SimSEE

BID – CONICYT (2007)

A tool to simulate the optimal operation of the power system:

- **Demands**
- **Generation plants (Hydro, Thermal, Solar, Wind)**
- **Network = Nodes and Arcs**
- **Interconnections**



El Sistema.

Generadores

Demandas

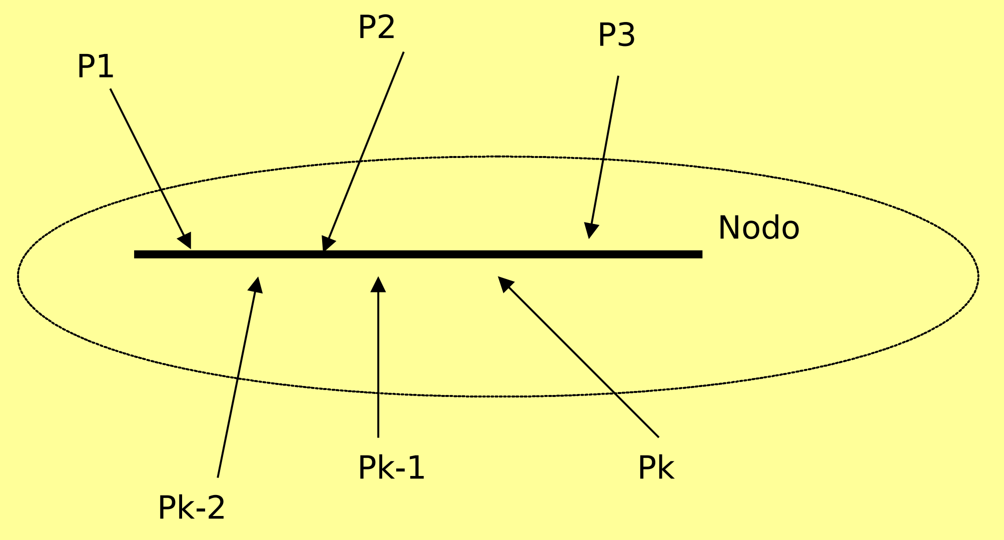
Red eléctrica

Interconexiones

Un simulador.

Una Herramienta

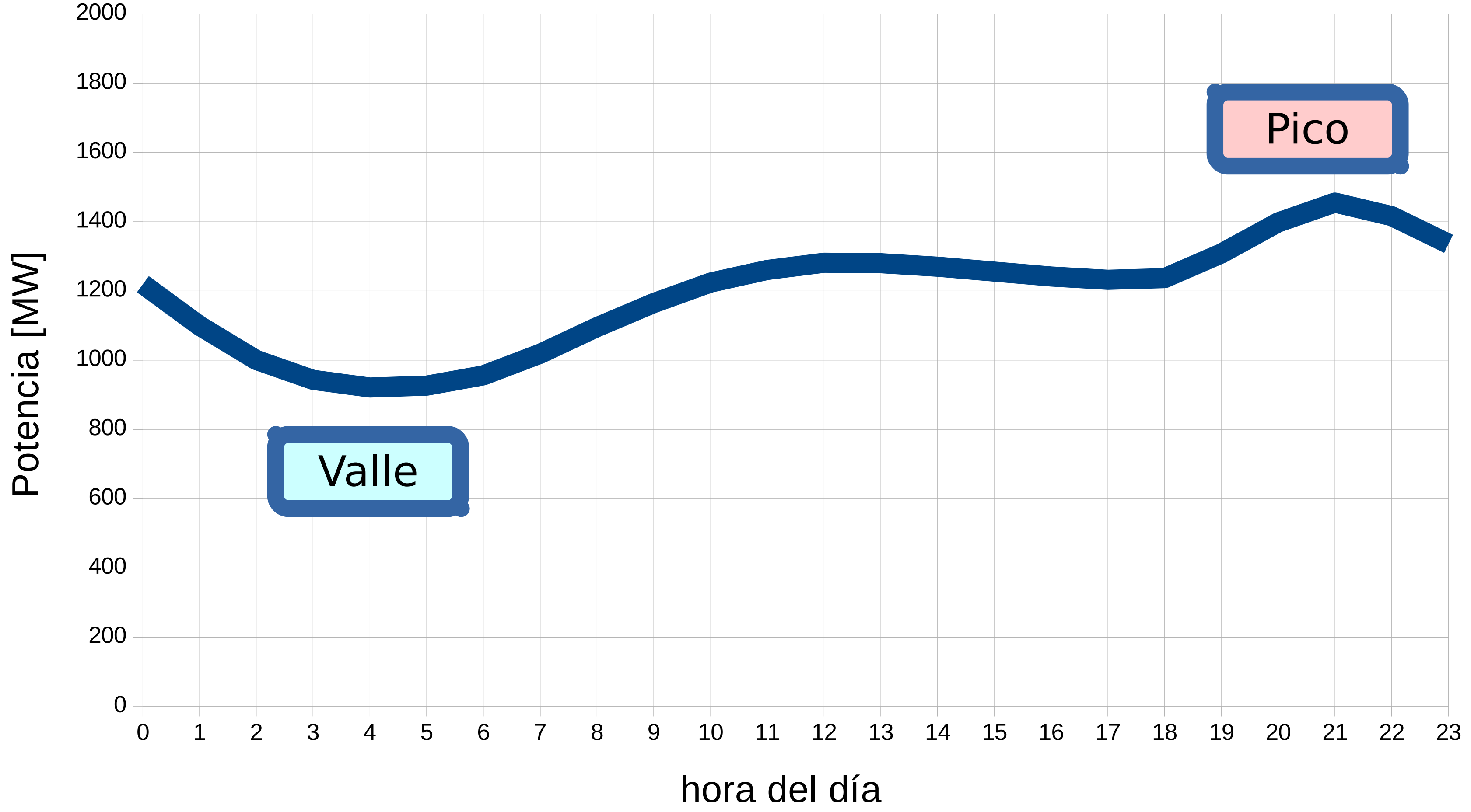
Despacho óptimo y restricción de balance de potencias.



$$\text{mínimizar}\left(\int_{t=t_0}^{\infty} \text{Costo(t)}\, dt\right)$$

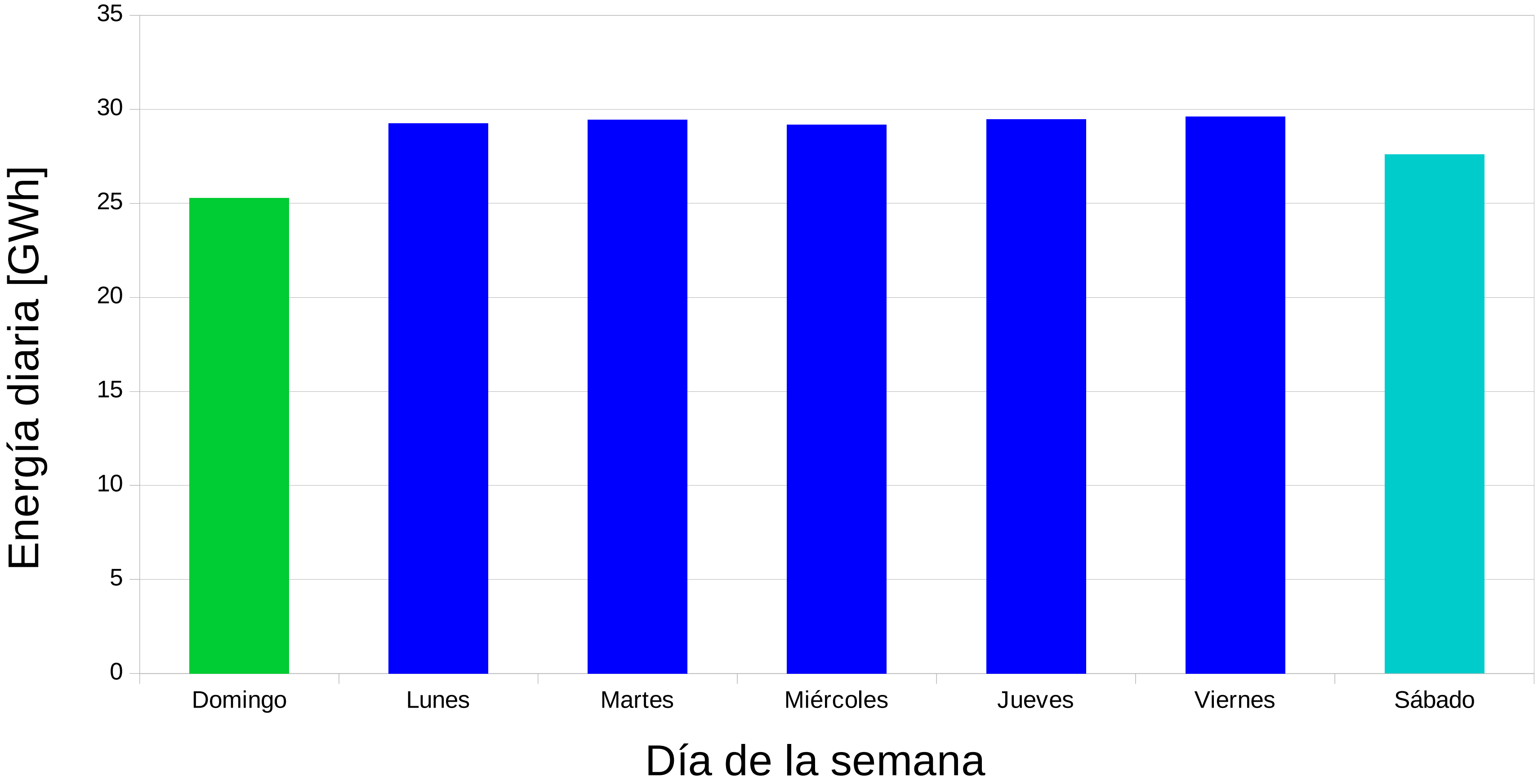
$$\text{sujeto } a: \sum_{k \in Actores} P_k = 0 ; \forall\, t$$

La Demanda.



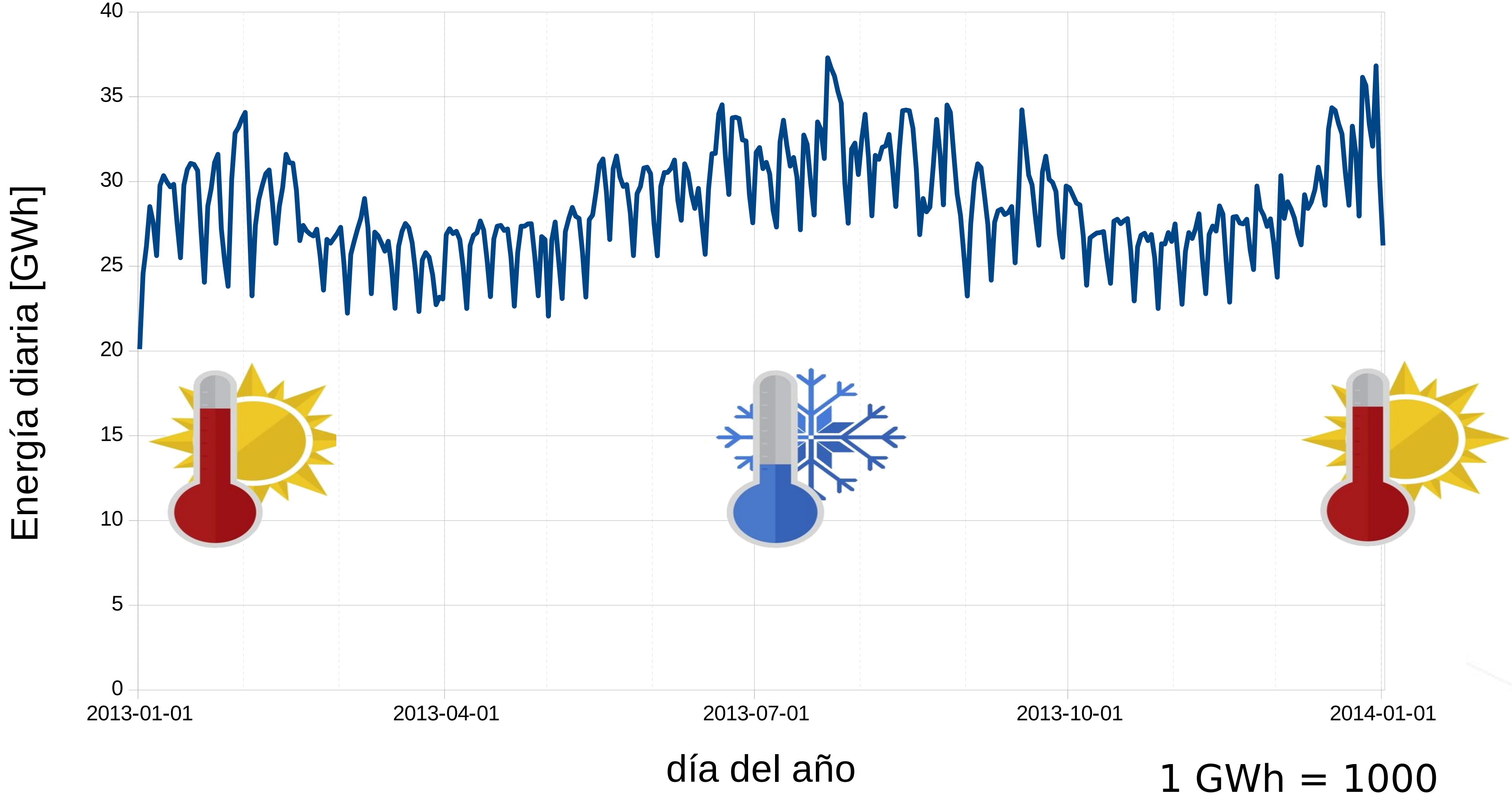
2000
1800
1600
1400
1200
1000
800
600
400
200
0
Potencia [MW]
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23
hora del día
Pico
Valle

La Demanda.



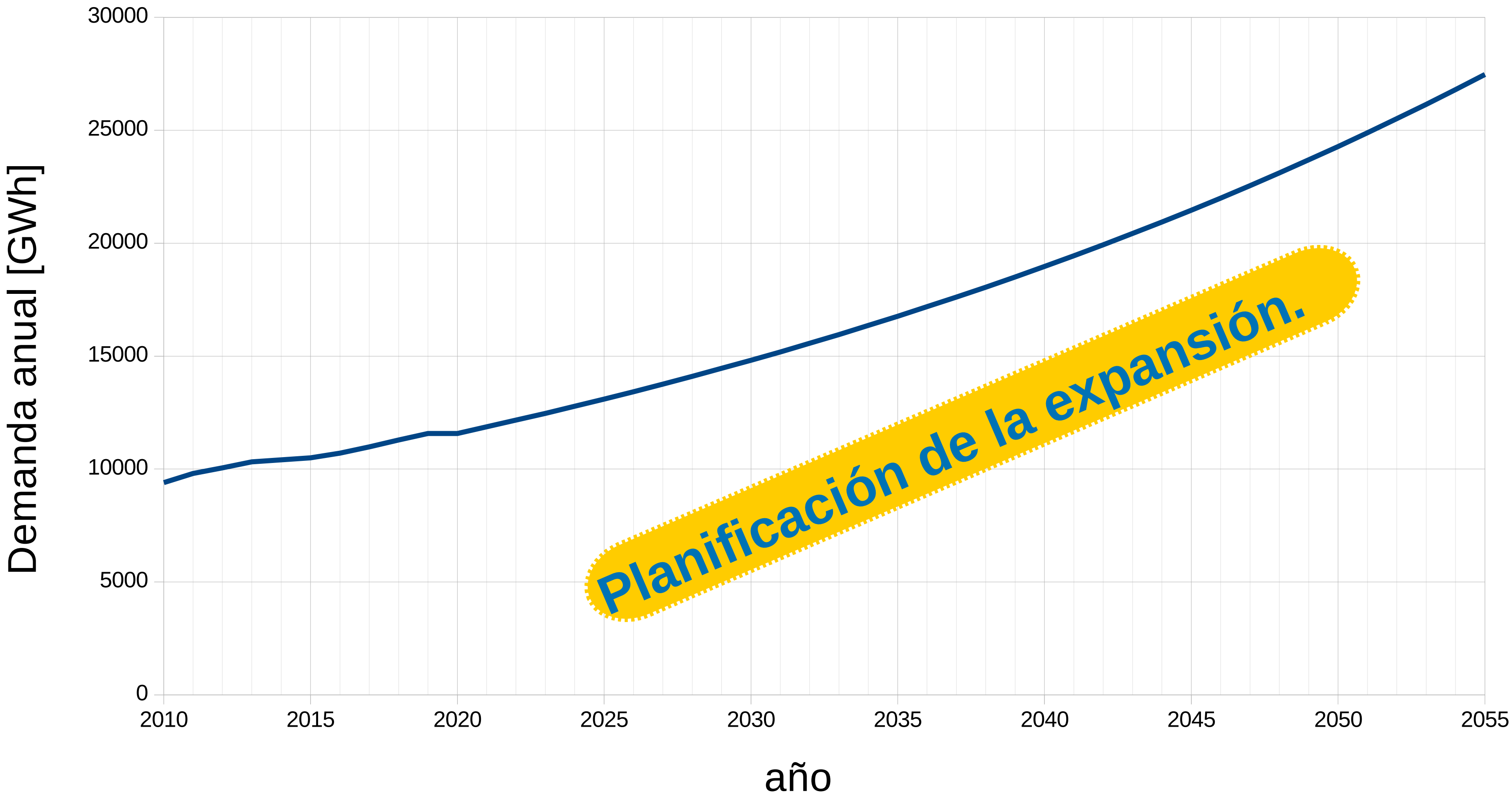
1 GWh = 1000 MWh

La Demanda.



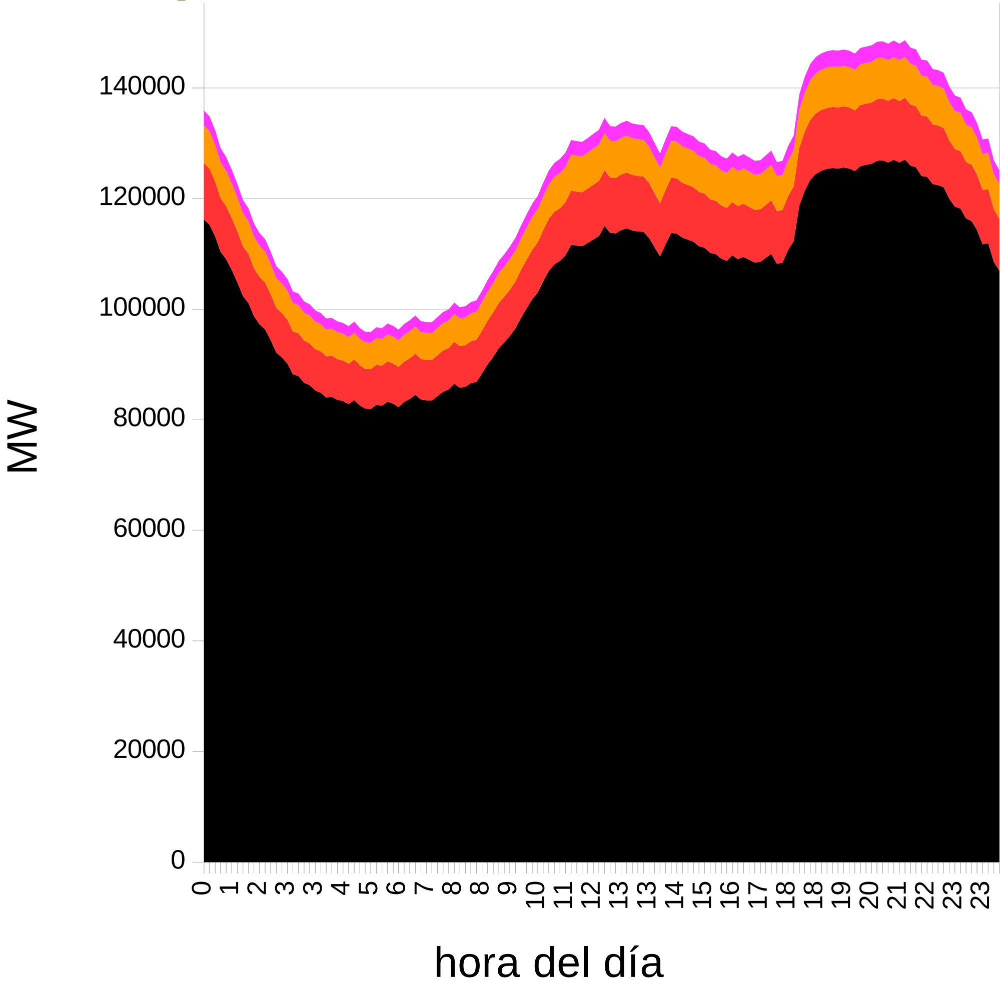
1 GWh = 1000 MWh

La Demanda.



30000
25000
20000
15000
10000
5000
0
Demanda anual [GWh]
2010
2015
2020
2025
2030
2035
2040
2045
2050
2055
año
Planificación de la expansión.

El costo de Racionamiento o Falla. Escalones y Costos de Falla. Máquinas de Falla.



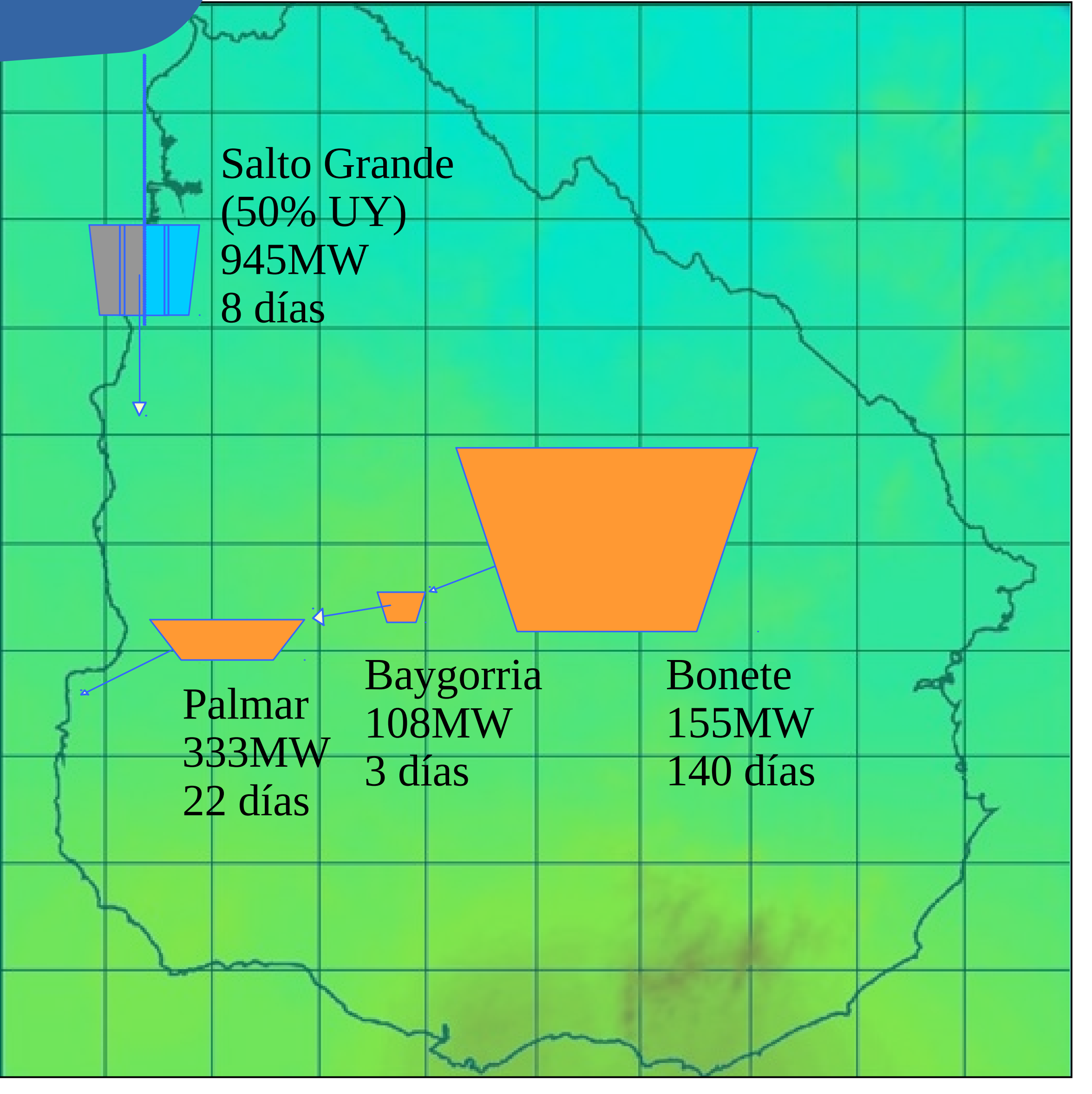
(02/04/2013) Decreto 105/013

- Escalón_F1(2%, CTR+10%)
- Escalón_F2(5%, 600 USD/MWh)
- Escalón_F3(7.5%, 2400 USD/MWh)
- Escalón_F4(85.5%, 4000 USD/MWh)

Estos valores determinan en el largo plazo la seguridad de abastecimiento.

Hidroeléctricas

1541 MW



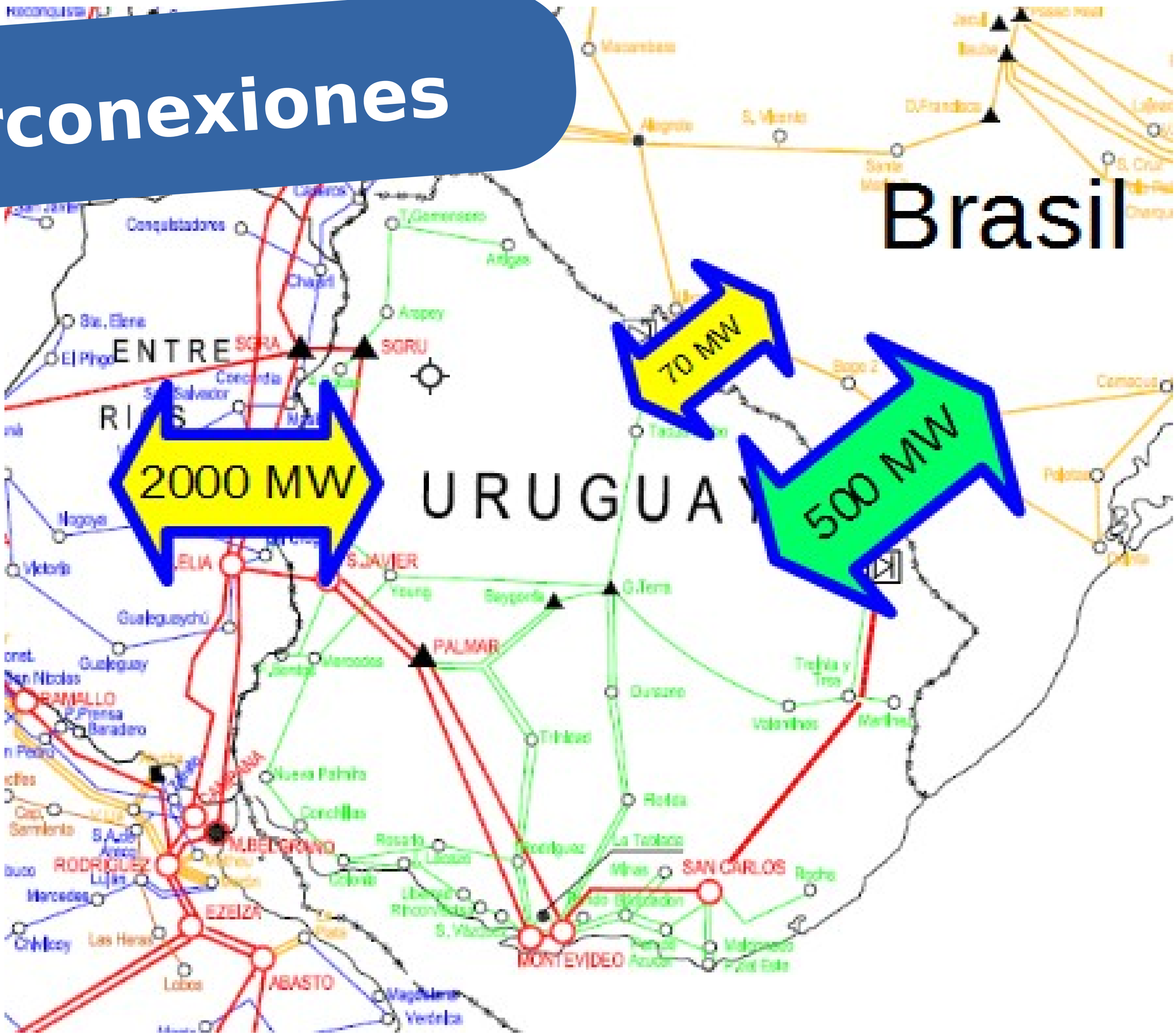
Los Recursos

Costos Variable = CV [USD/MWh] = combustible + O&M variable
valor expresado en dólares por MWh entregado

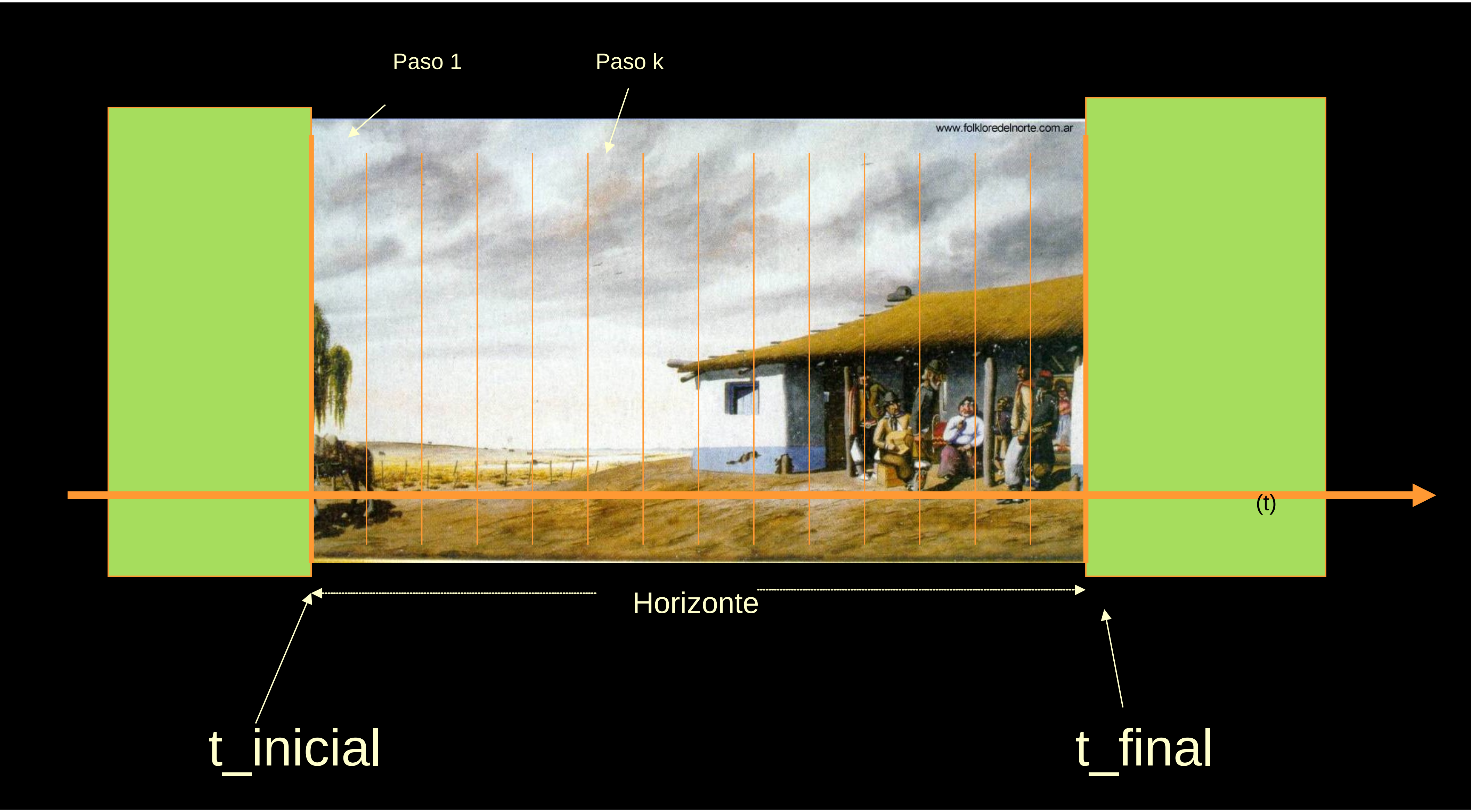
Costos Fijos = CF [USD/MWh] = Inversión + O&M fija
valor expresado en dólares por MW y por hora disponible.

	CF	CV	
	USD/MWh	USD/MWh	
Eólica	60	0	
Solar	55	0	
TG	15	180	@(WTI =70)
CC	20	120	@(WTI =70)
Biomasa	65	60	

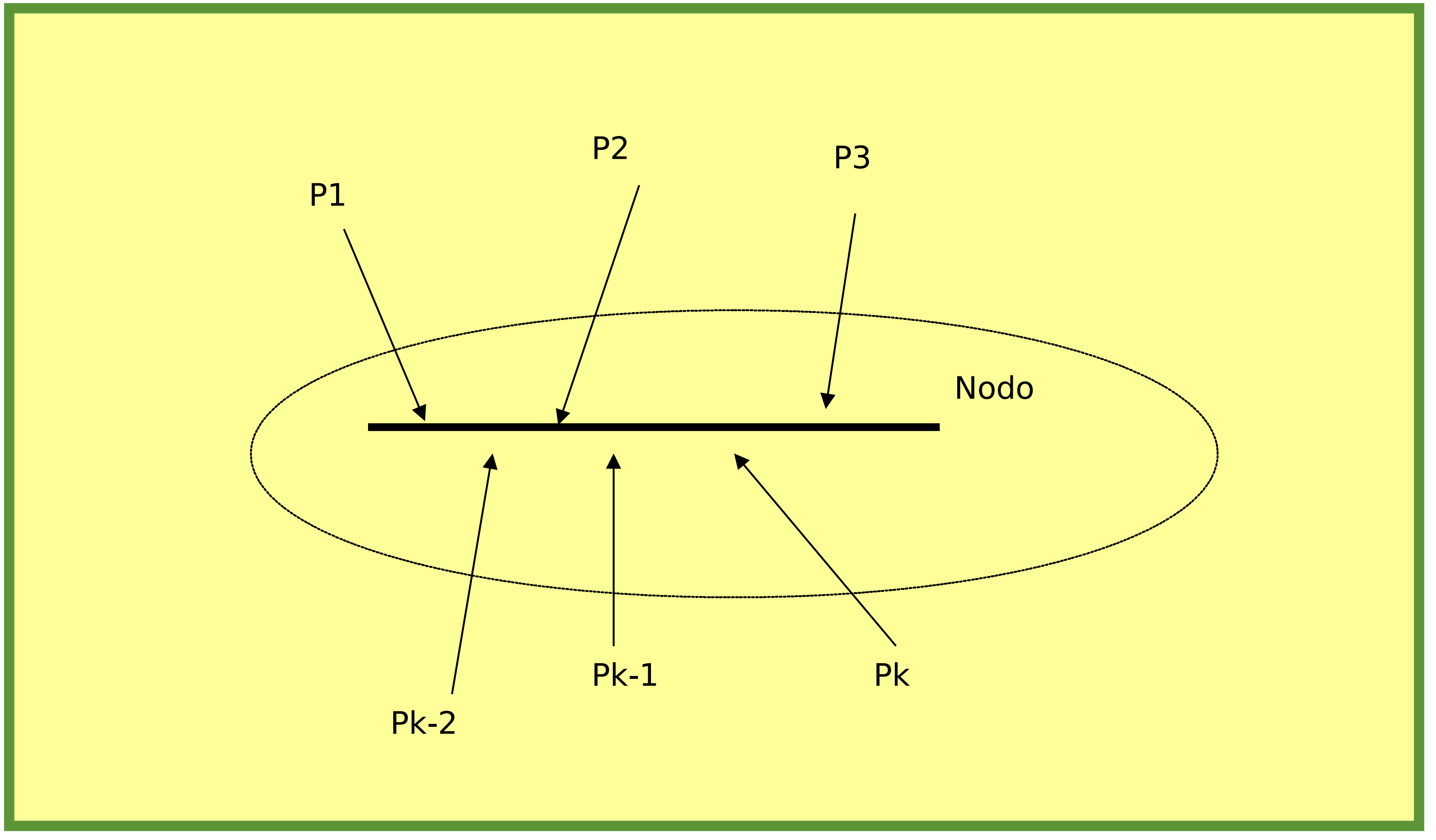
Interconexiones



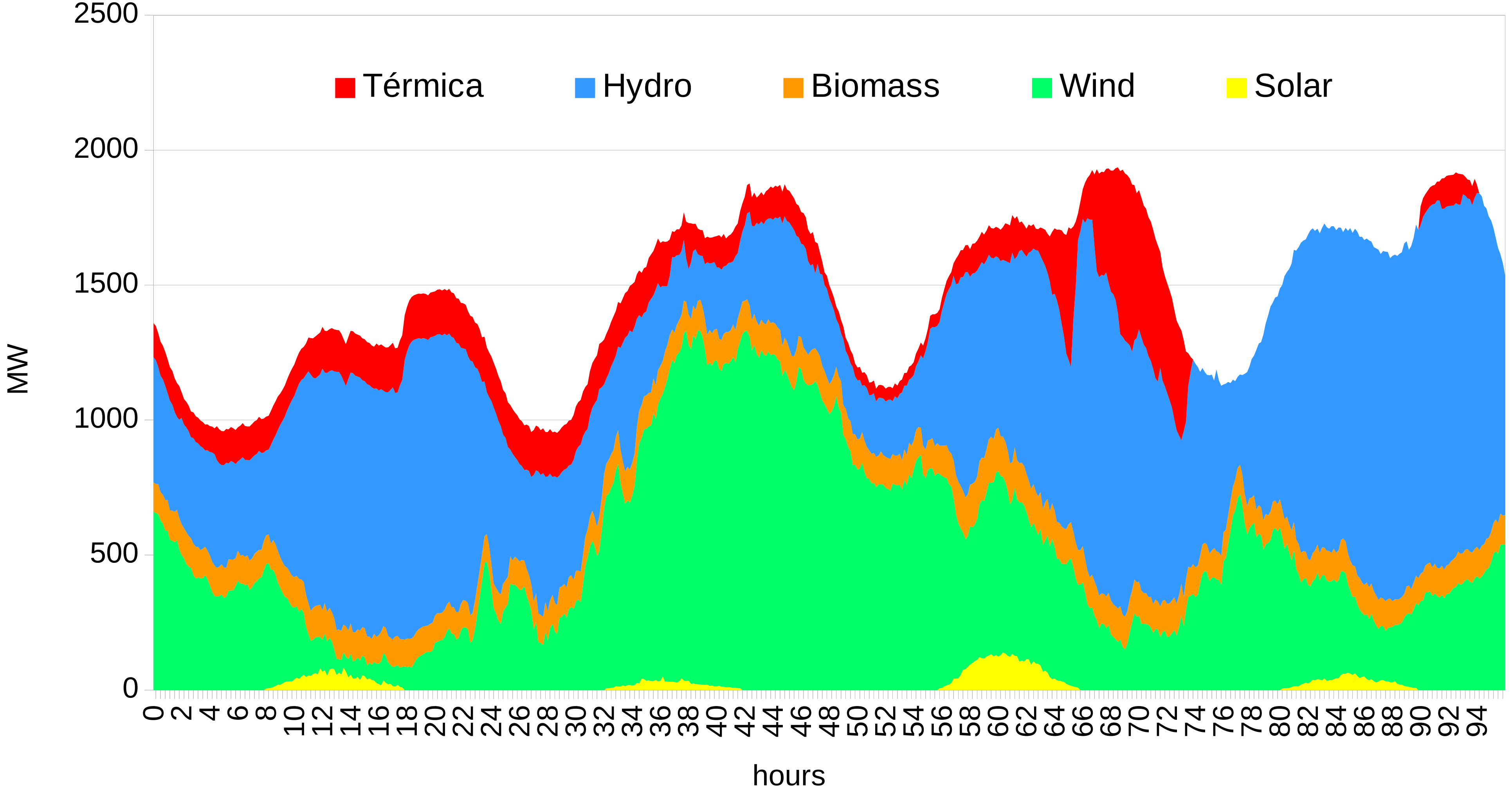
Horizonte y Paso de simulación



Restricción de Balance de potencias. Paso y Postes (Bandas horarias).

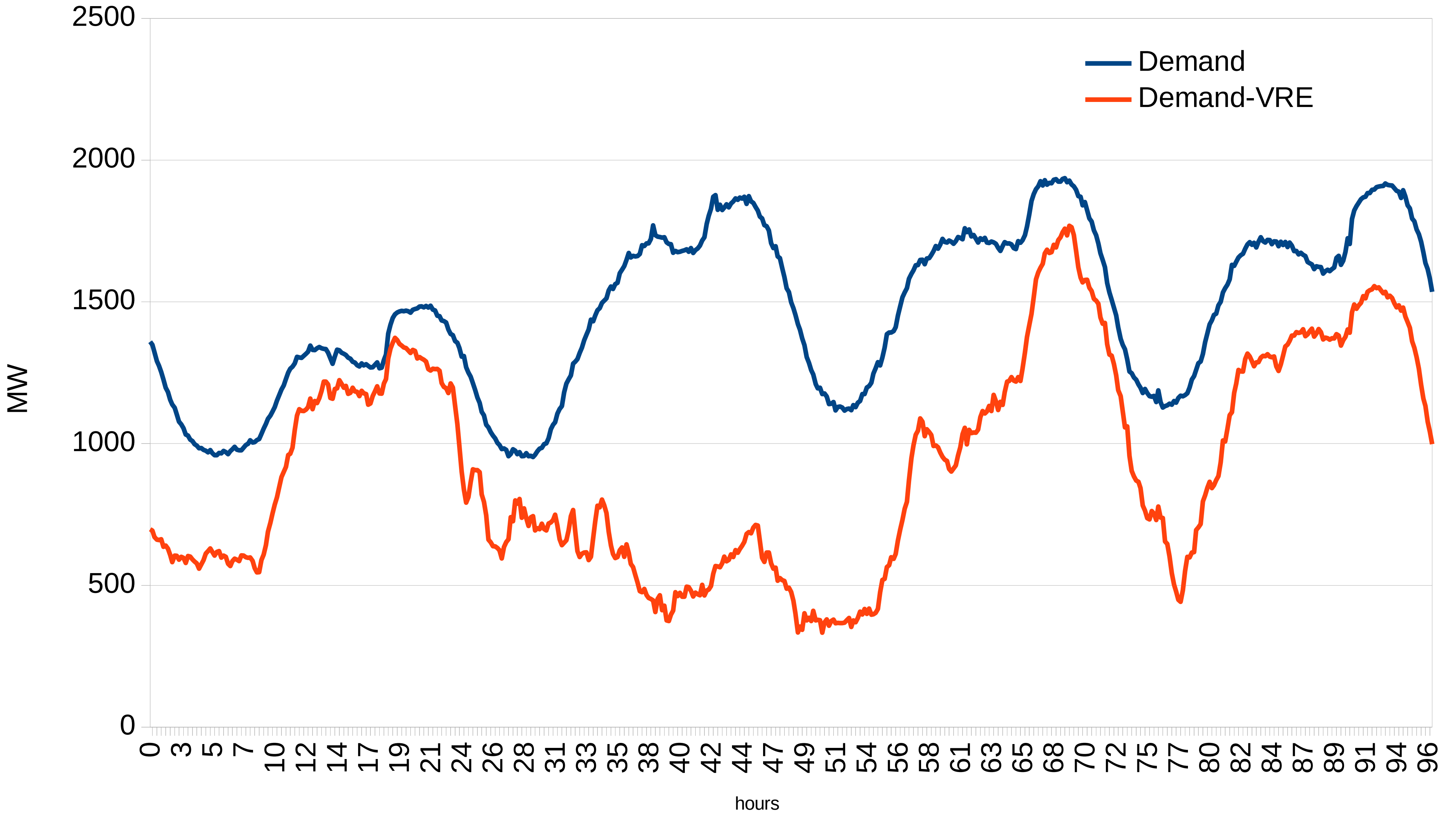


Uruguay - Composition of the energy supply of the first days of July-2018.



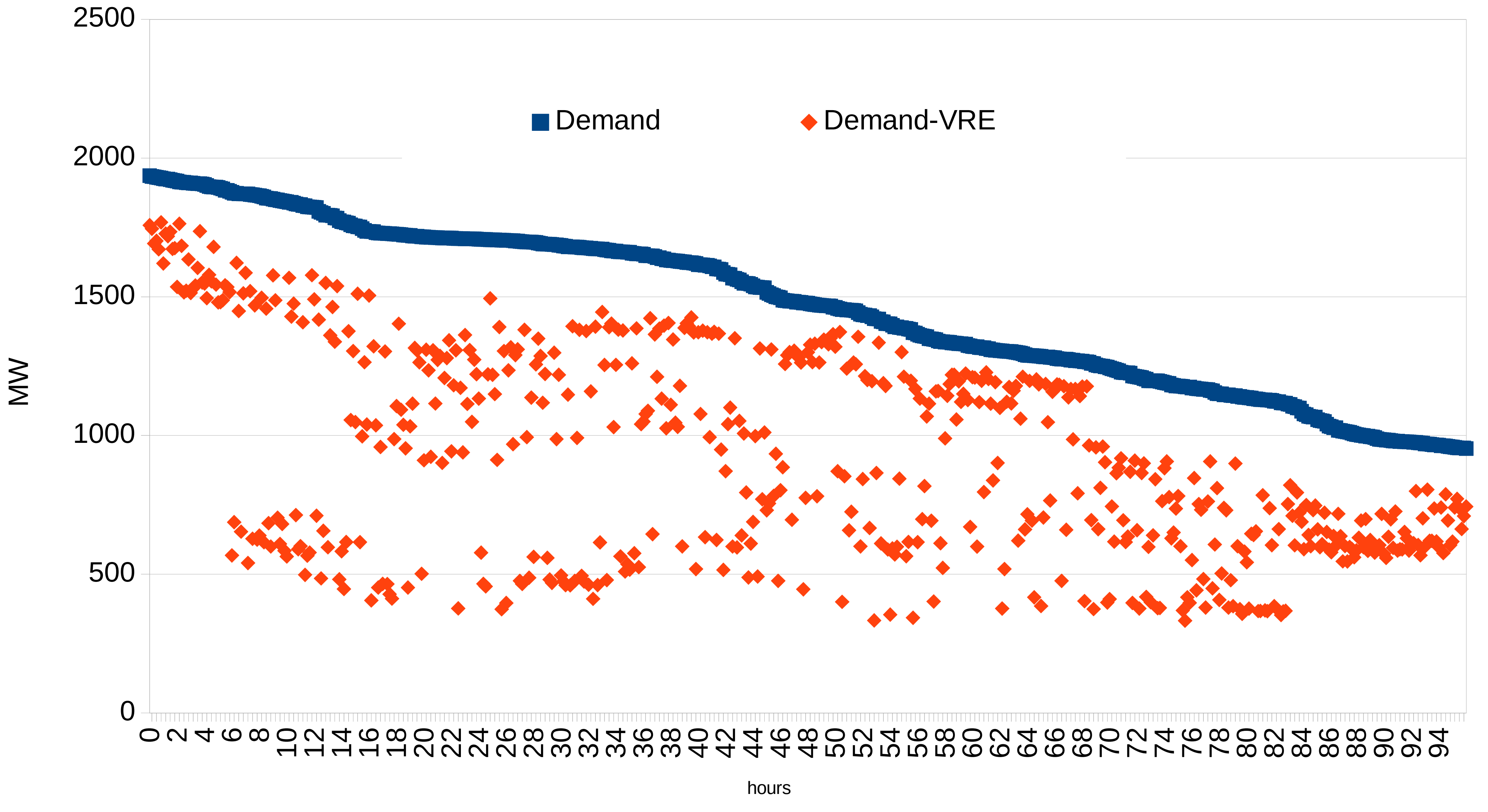
Source: ADME - SCADA tenminute time series

Uruguay - Demand and Net-Demand first days of July-2018.



Source: ADME - SCADA 10-minute time series

the monotonous load curve ... Makes sense?

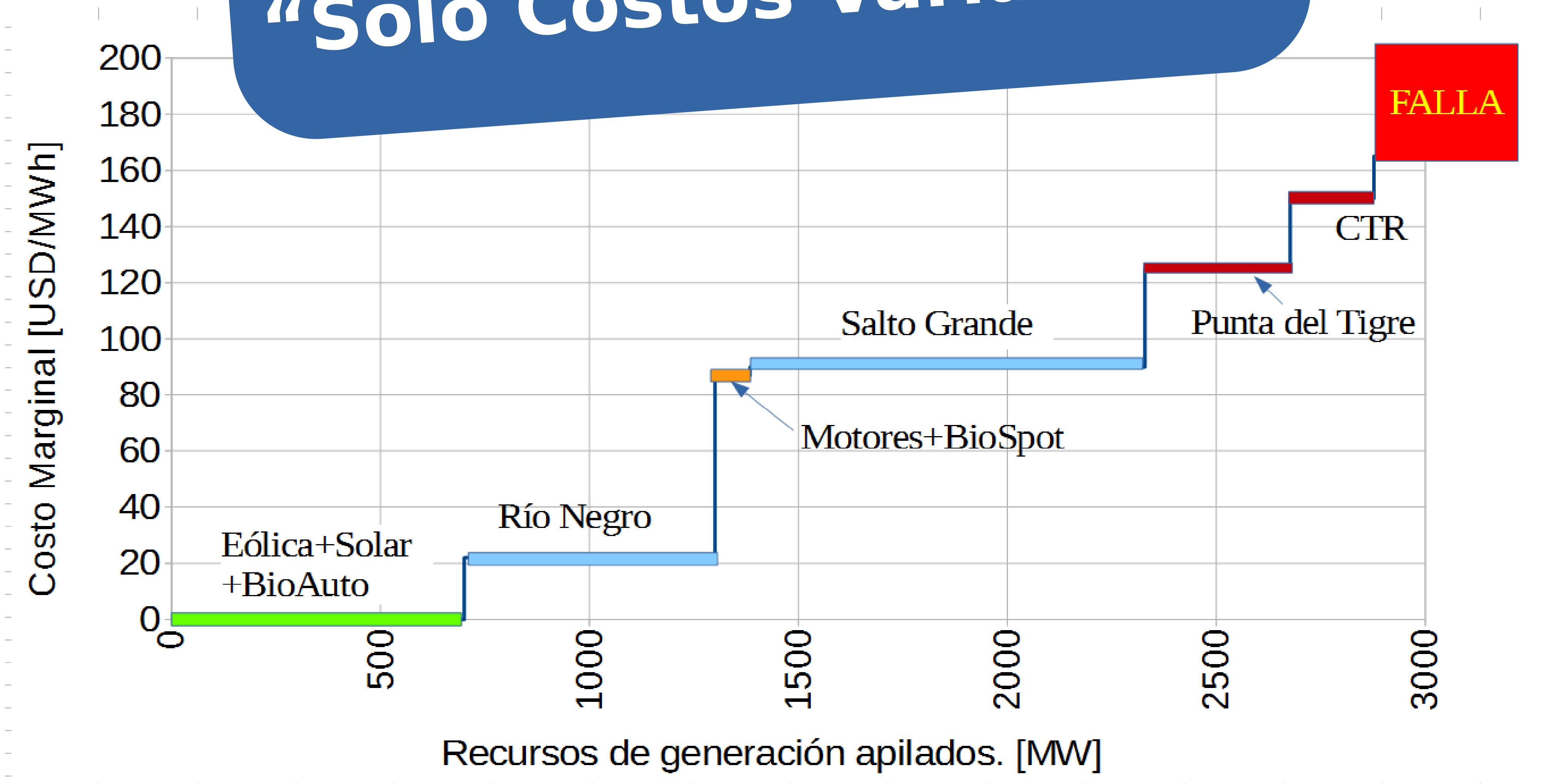


Source: ADME - SCADA 10-minute time series

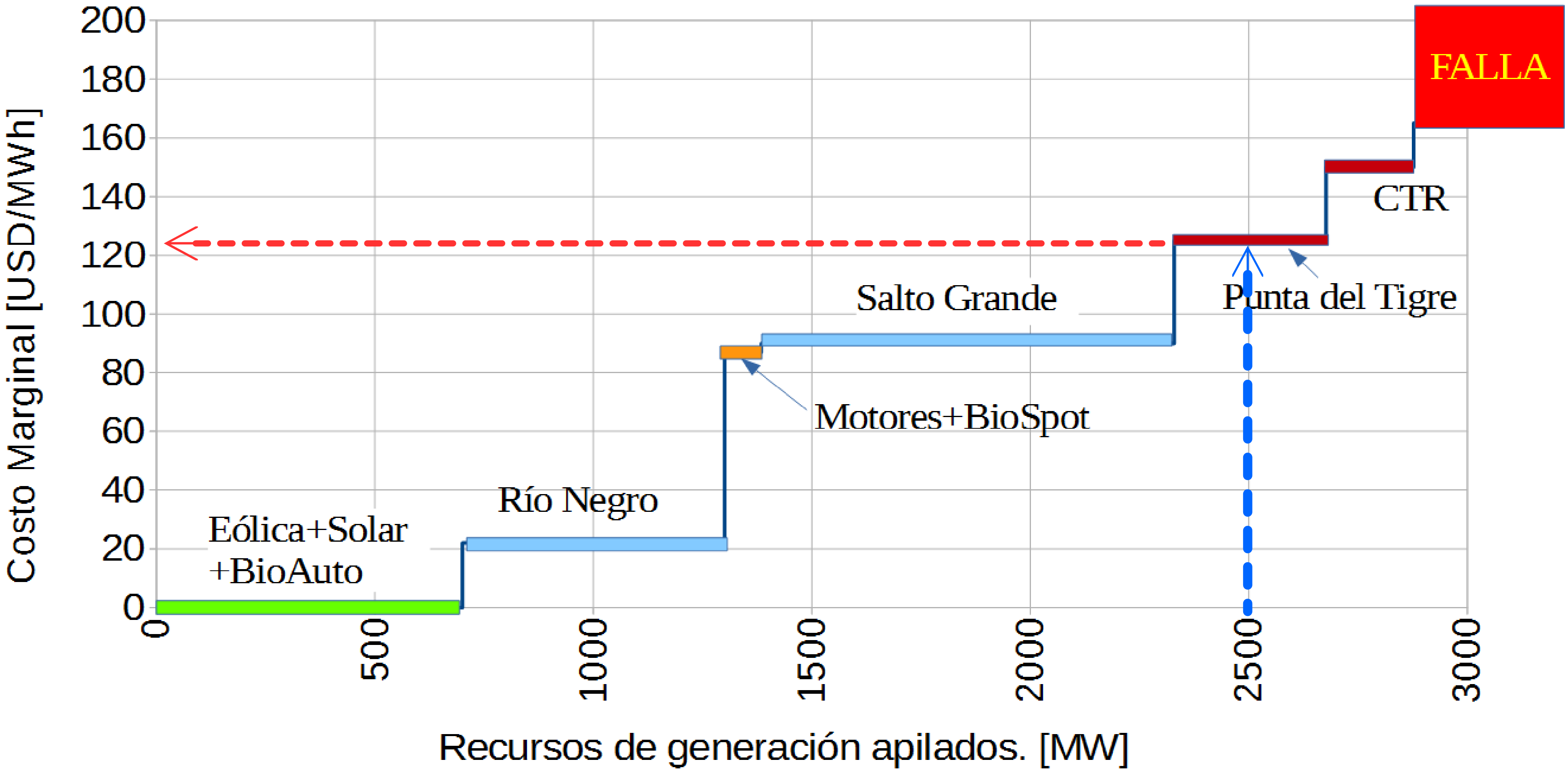
The Time Bands handling in SimSEE.

- **SimSEE allows the configuration of a time-step divided into time bands, it also allows defining what Demands and what Resources are considered during the simulation to create the Net Demand and thus dynamically define the grouping of the hours of the step in the different bands.**
- **It is a good solution if you need to maintain a step of time greater than an hour.**
- **At the generation level, the requirement is clearly given by the net demand, but at the level of distribution, the requirements are those of the demand of the system.**
- **When the expansion of the transmission lines is considered in the planning problem, I believe that going to a time step of one hour is obligatory as well as forgetting the use of time bands.**
- **Therefore, the tendency is to stop using the time bands by going to the use of simulations with a time-step of one hour.**

Despacho Óptimo
Primer Principio:
“Sólo Costos Variables”



Orden de mérito. y Costo Marginal.



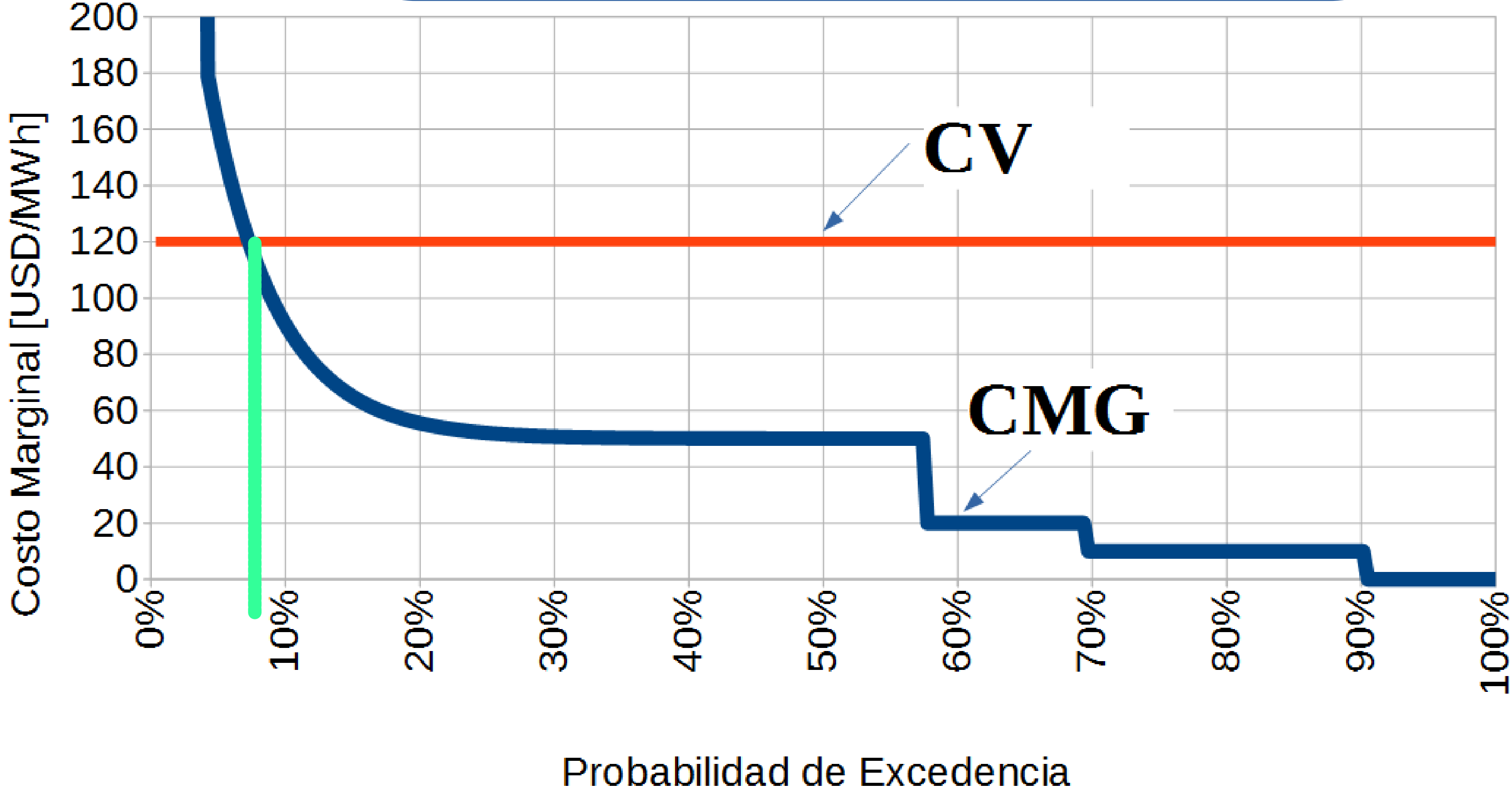
Precio Spot.

Precio SPOT = mín(CMG, 250)

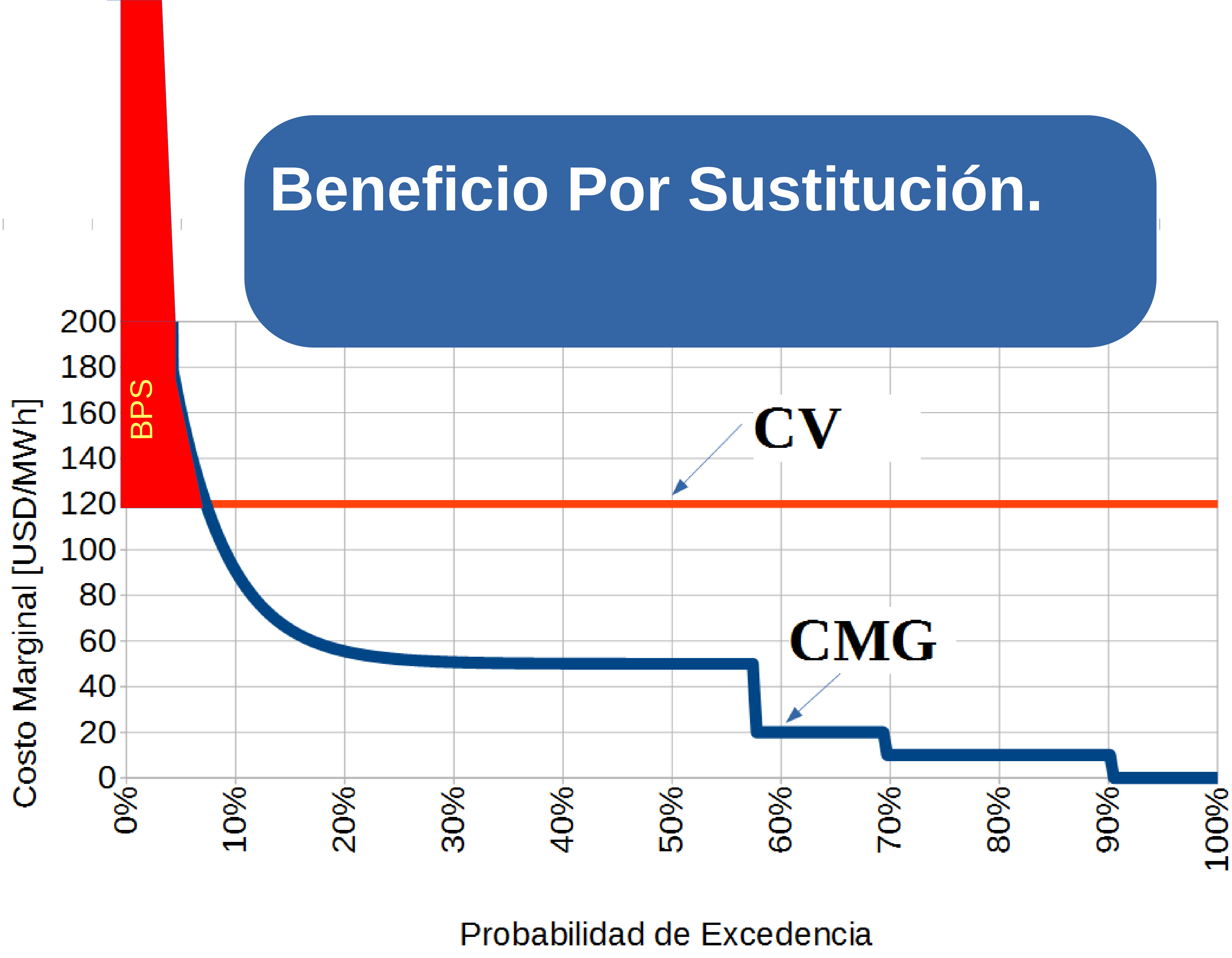
Los recursos forzados NO forman precio.
Las exportaciones ocasionales No forman precio.
Las importaciones si forman precio.

ADME sanciona el Precio Spot con detalle horario.

Costo Marginal, CV y Factor de Despacho.



Beneficio Por Sustitución.



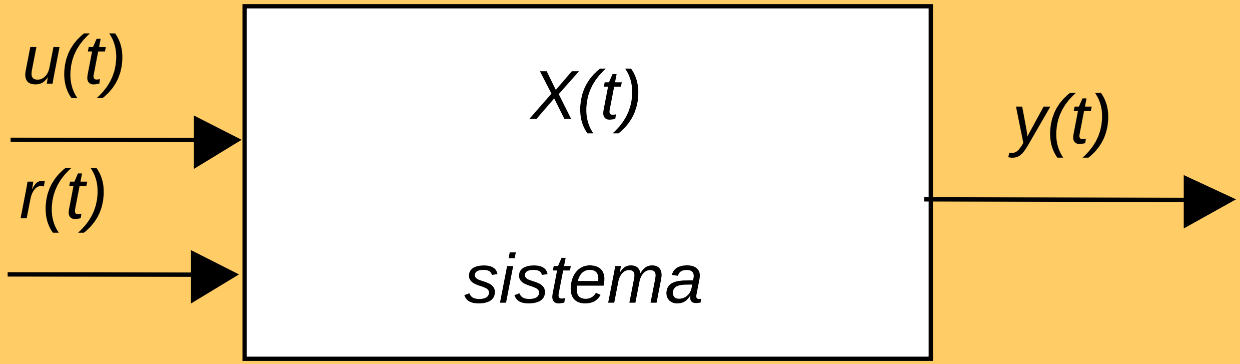
Despacho Óptimo
Segundo Principio:
“Los contratos son de papel”

Estado del Sistema

$$X(t) = \begin{bmatrix} x_1 \\ x_2 \\ \dots \\ x_n \end{bmatrix}$$

Vector de información que capta todo lo relevante del pasado para calcular el futuro si se conocen las entradas de aquí en mas.

Sistema Dinámico. Diagrama de bloques



u , ***entradas controlables***
r , ***entradas no controlables***
x , ***estado***
y , *variables observadas o* ***salidas***
t , ***es el tiempo.***

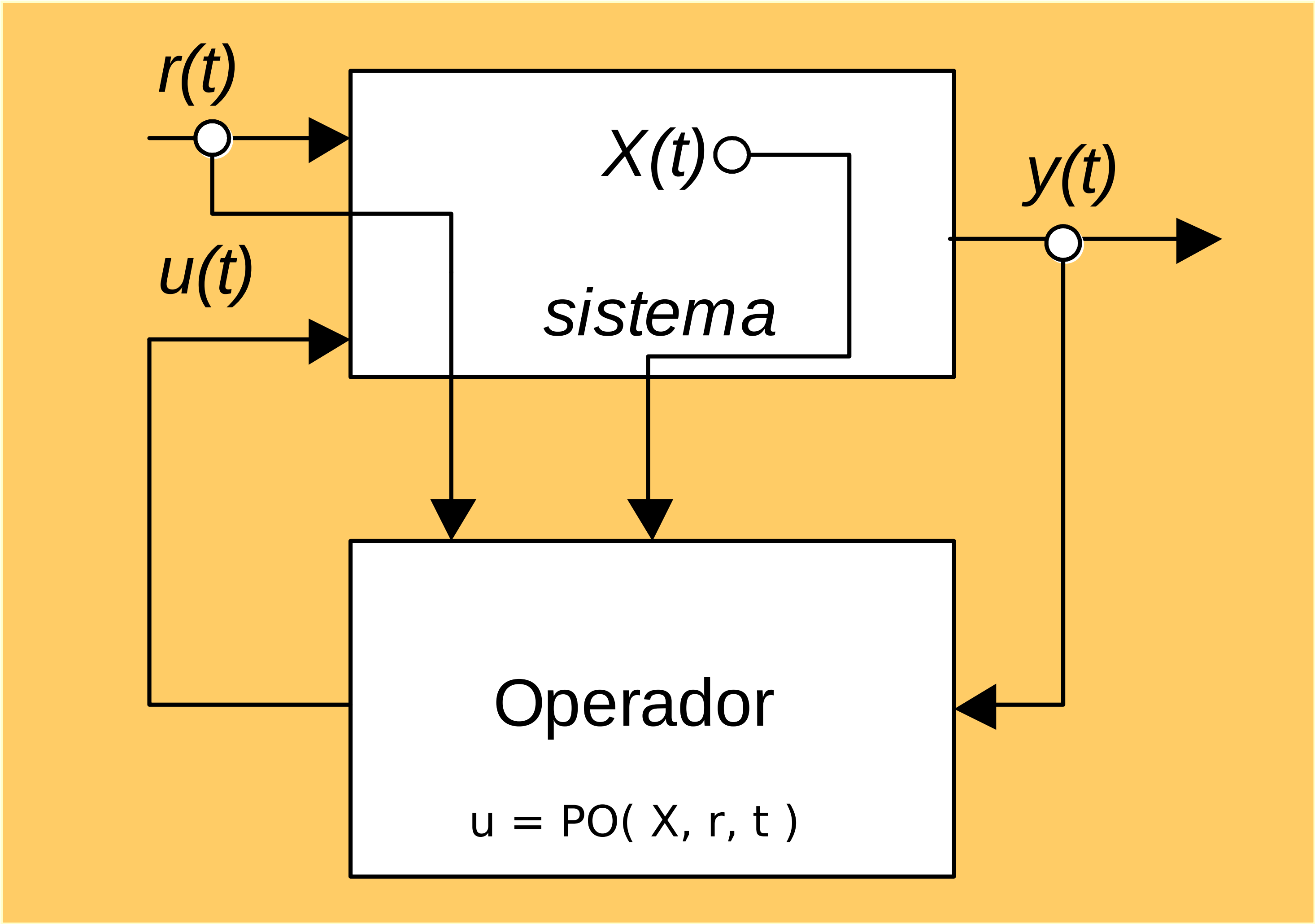
Ecuación de transición.
Ecuación de evolución del Estado.

$$\dot{x} = f(x, u, r, t)$$

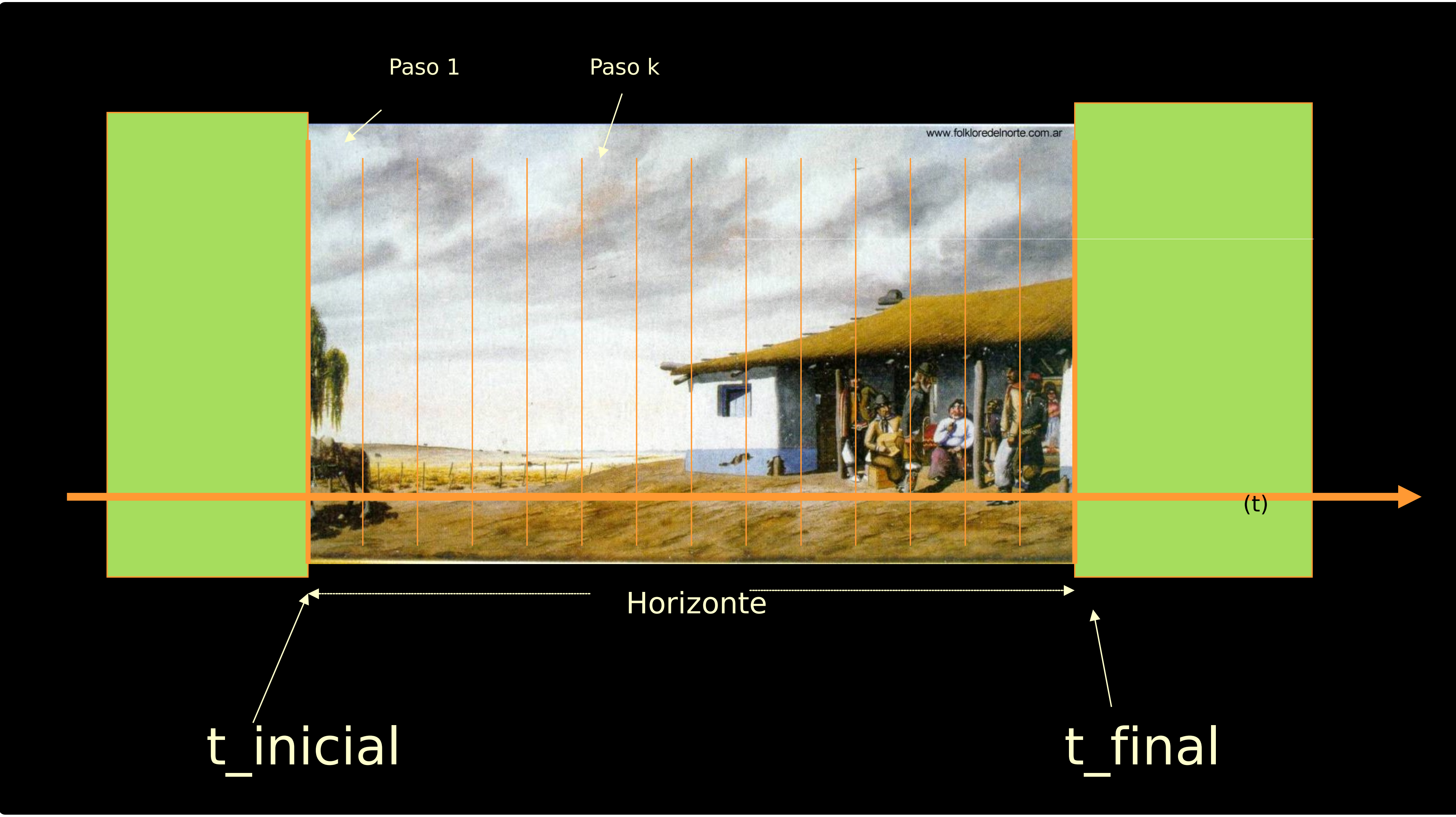
$$y = g(x, u, r, t)$$

u , ***entradas controlables***
r , ***entradas no controlables***
x , ***estado***
y , *variables observadas o* ***salidas***
t , ***es el tiempo.***

Operación del sistema.



Horizonte y Paso de simulación



Costo Futuro = CF

Costo Futuro = CF

$$CF_k = \sum_{j=k}^{j=\infty} \left(cc_j + cd_j + ci_j - ie_j \right) \cdot q^{j-k}$$

cc = costo de combustible
cd = costo de déficit
ci = costo de importaciones
ie = ingresos por exportaciones

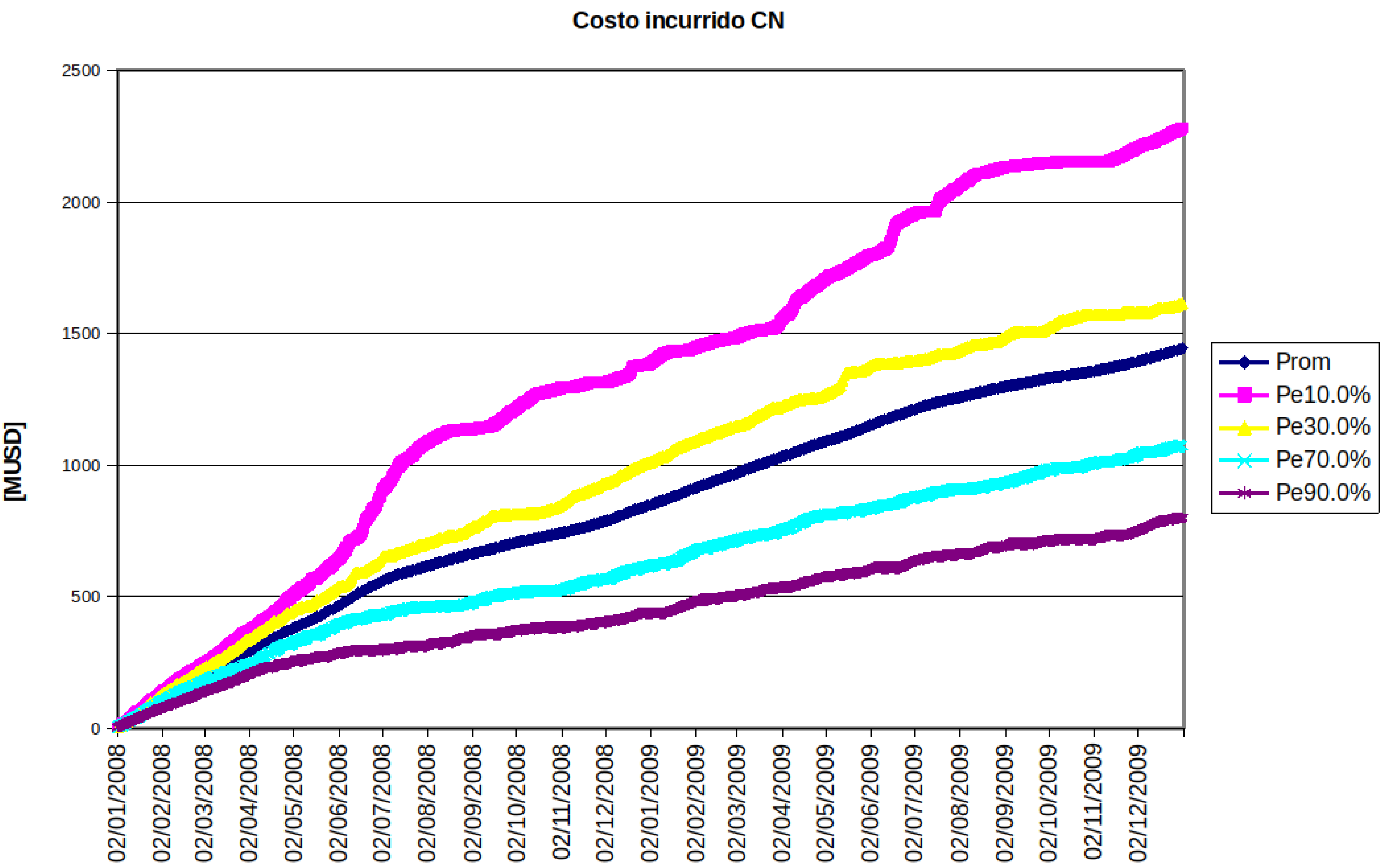
q = factor de actualización.

Política de Operación

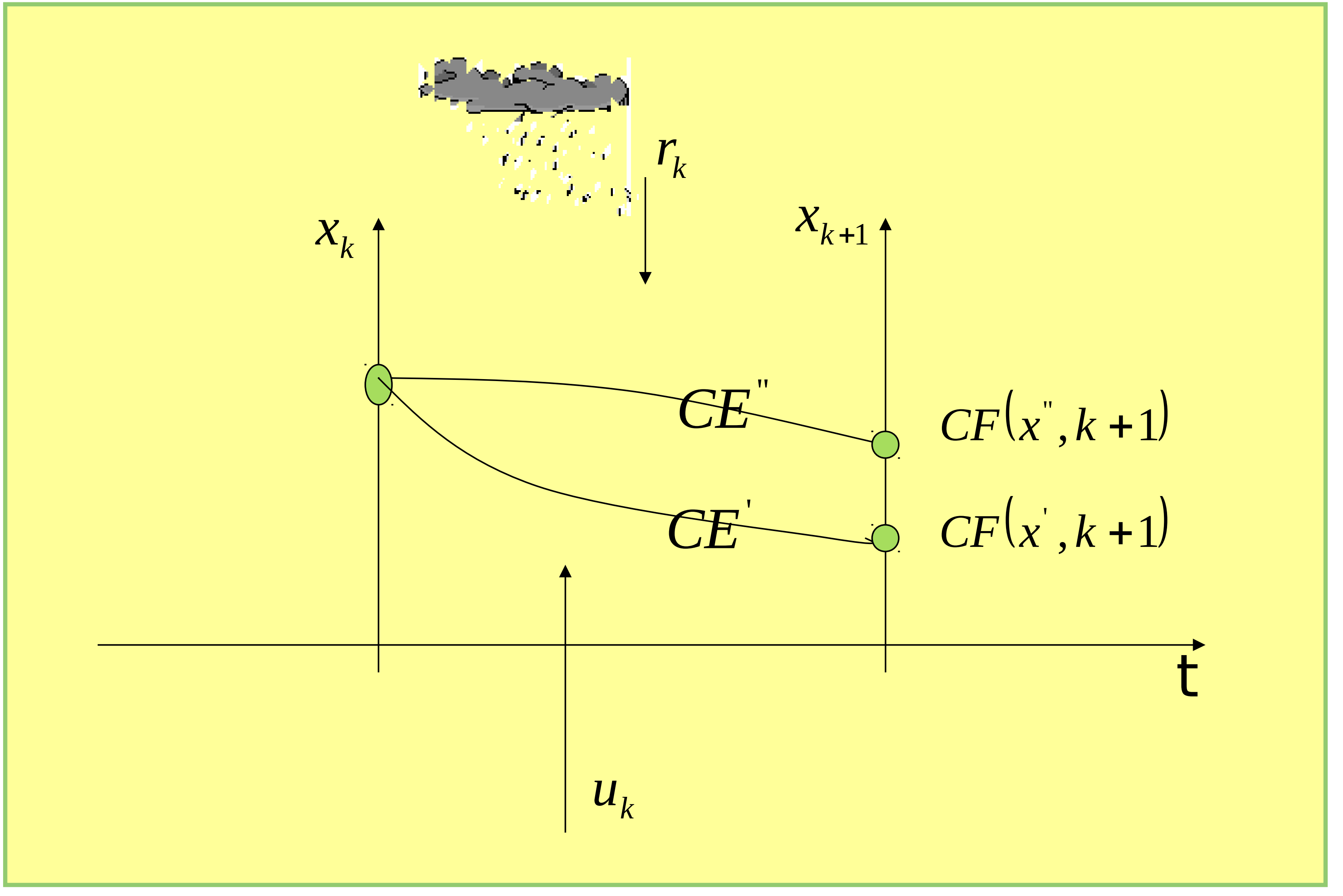
$$u = PO(X, r, t)$$

$$CF_{PO}(X_{ahora}) = \langle \int_{ahora}^{+\infty} ce(X, r, u, t)\, dt \rangle$$

Costo de suministro de la demanda eléctrica Uruguay 2008



Programación Dinámica Estocástica.



Valor de un recurso almacenable

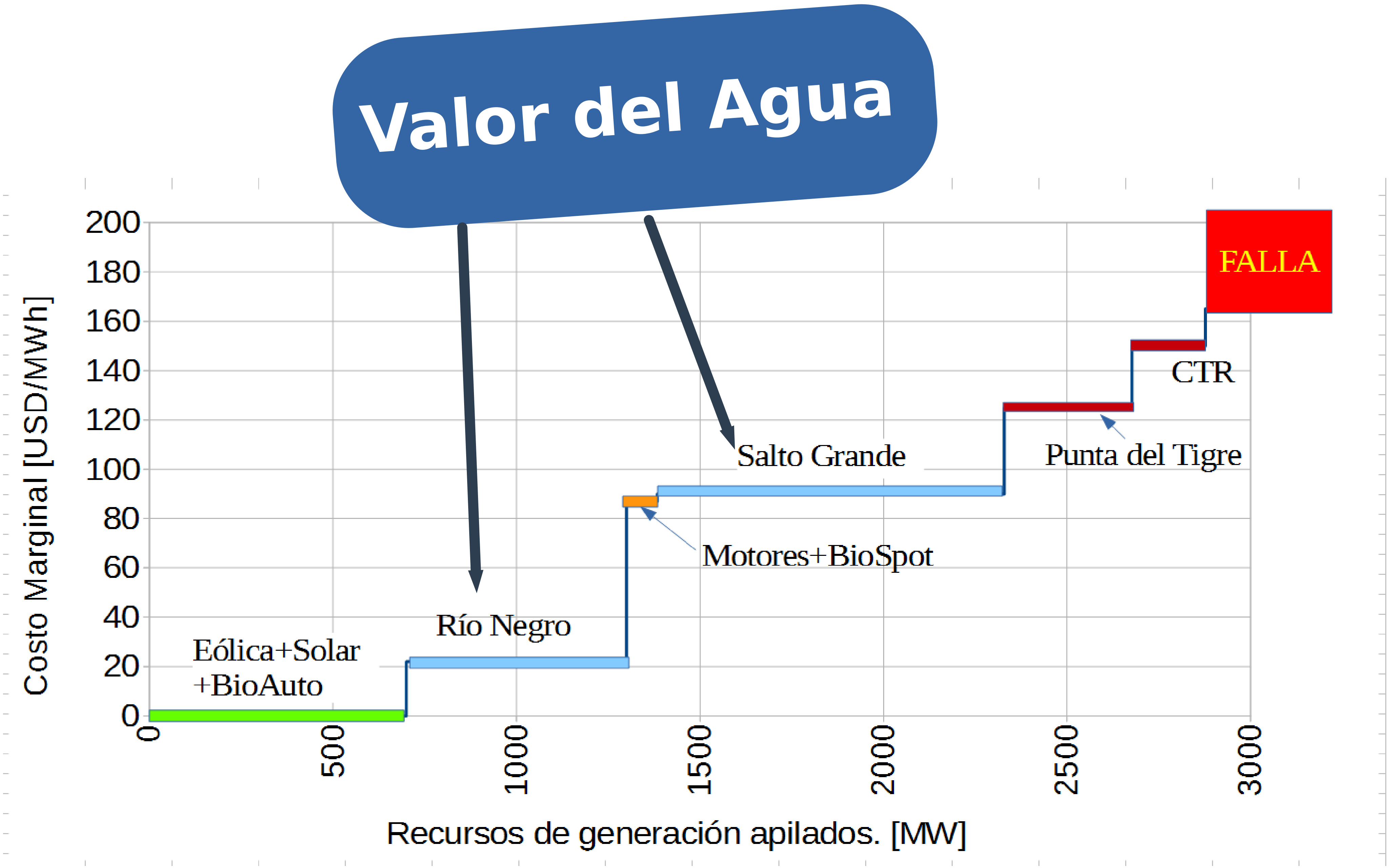
Comparación entre costo del presente y costo del futuro.

De no haber restricciones para el traslado en el tiempo, el costo marginal sería el mismo en todas las horas del futuro.

INCERTIDUMBRE DEL FUTURO.

MODELOS ESTOCASTICOS

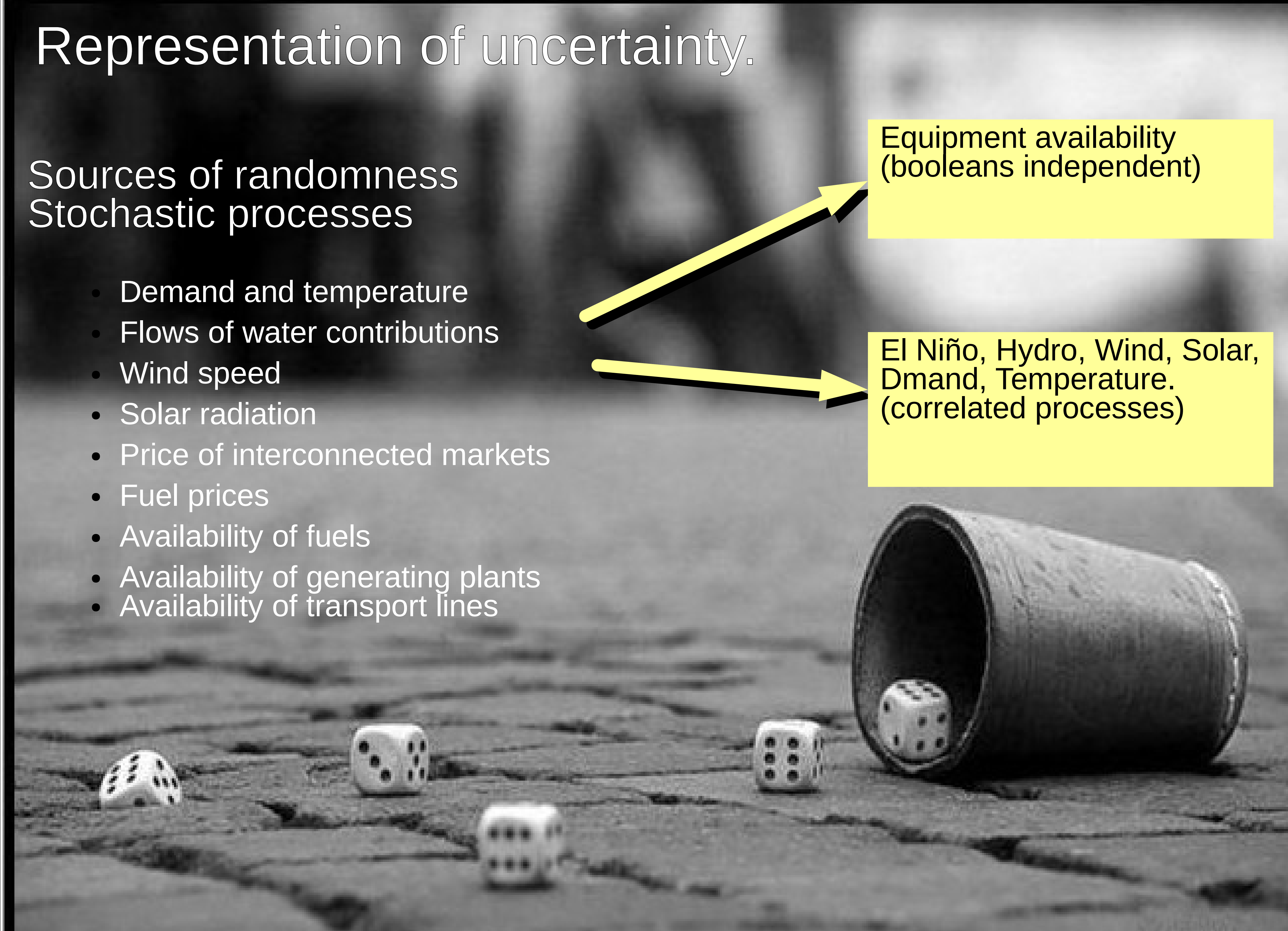
PRONOSTICOS


Valor del Agua
FALLA
CTR
Punta del Tigre
Salto Grande
Motores+BioSpot
Río Negro
Eólica+Solar
+BioAuto
Costo Marginal [USD/MWh]
0
20
40
60
80
100
120
140
160
180
200
0
500
1000
1500
2000
2500
3000
Recursos de generación apilados. [MW]

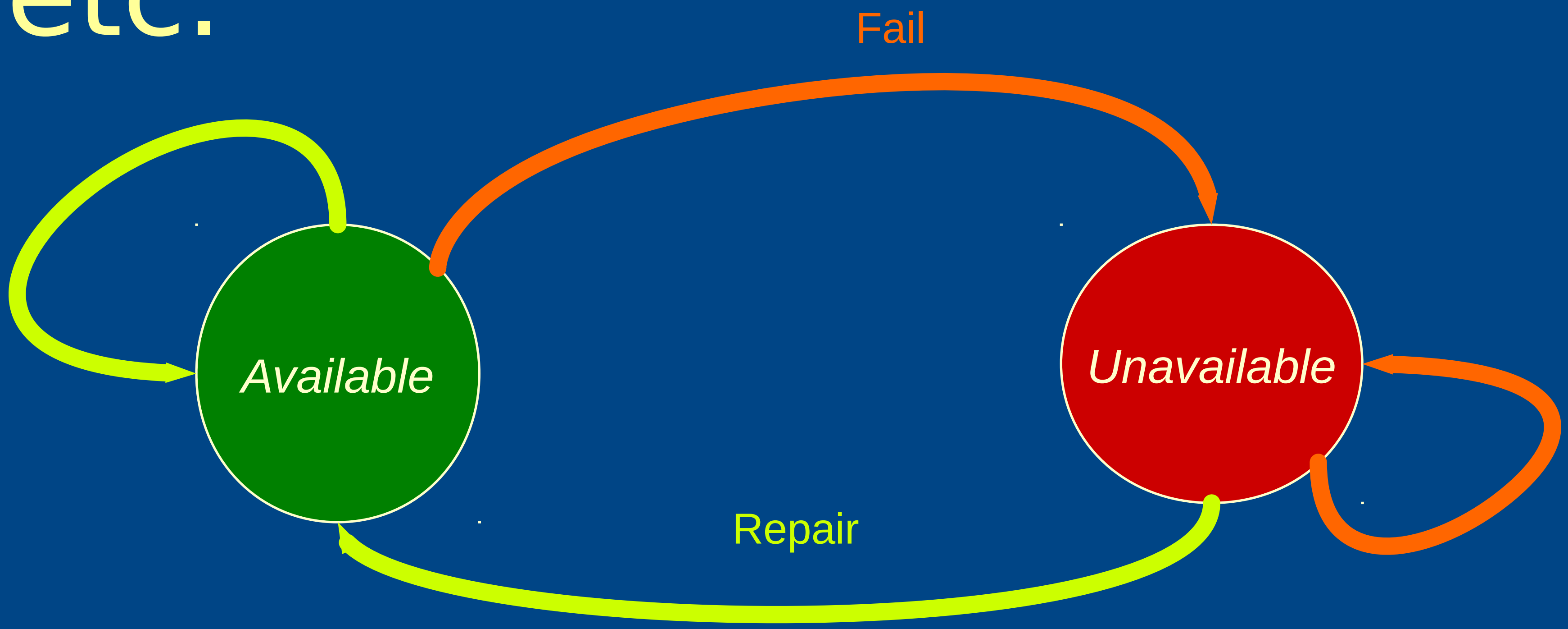
Valor del STOCK

Si pensamos que cada *x* representa un stock de un recurso (por ejemplo agua embalsada) las derivadas del costo futuro respecto de cada variable, puede pensarse como menos el valor que le asignamos a una unidad de stock de esa variable. Generalmente aumentar el stock de un recurso disminuirá el costo futuro por lo que estas derivadas son negativas.

$$valor\ de\ x = -\frac{\partial CF(x, k+1)}{\partial x}$$


Representation of uncertainty.
Sources of randomness
Stochastic processes
• Demand and temperature
• Flows of water contributions
• Wind speed
• Solar radiation
• Price of interconnected markets
• Fuel prices
• Availability of fuels
• Availability of generating plants
• Availability of transport lines
Equipment availability
(booleans independent)
El Niño, Hydro, Wind, Solar,
Dmand, Temperature.
(correlated processes)

Availability of generators, power transmission lines, etc.



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

Each unit adds a Boolean state variable to the system.

CEGH modelling.

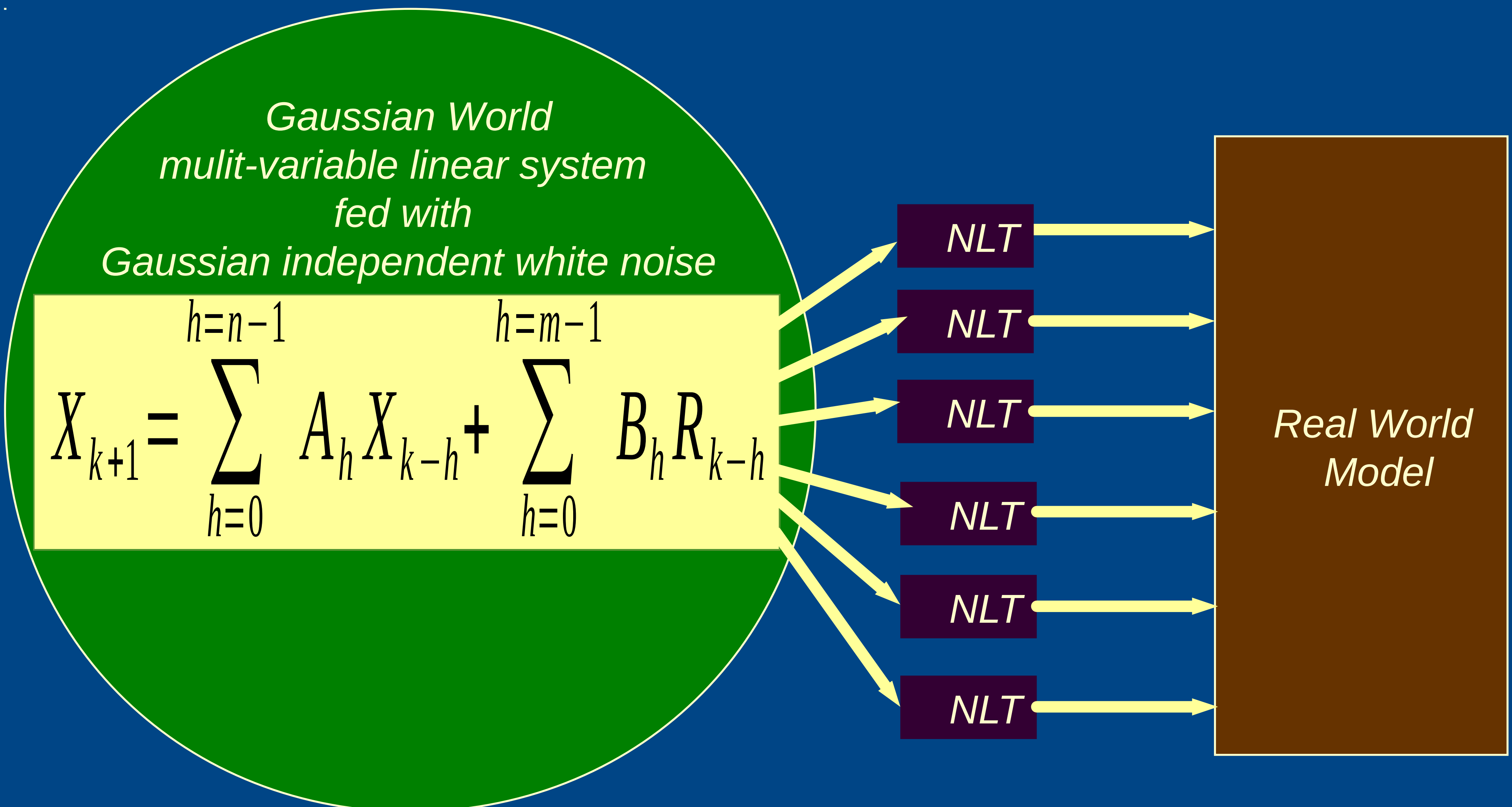
It is at this point that SimSEE make the diferece from other simulators. The CEGH models allow the joint modeling of multiple variables capturing the spatial and temporal correlations.

At present, we use these models to represent the water inflows to the dams in conjunction with the El Niño phenomenon, the production of wind and solar plants, the temperature, and the price of a barrel of oil.

Another fundamental aspect of CEGH models is that they naturally allows introducing the available information of forecasts.

CEGH modelling.

- Conserve amplitude histograms.
- Keep spatial and temporal correlations.



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

Bellman's curse of dimensionality.

Decreasing the time step of the simulation, to model faster dynamics, involves increasing the size of the state space of the system and very quickly the problem is computationally intractable.

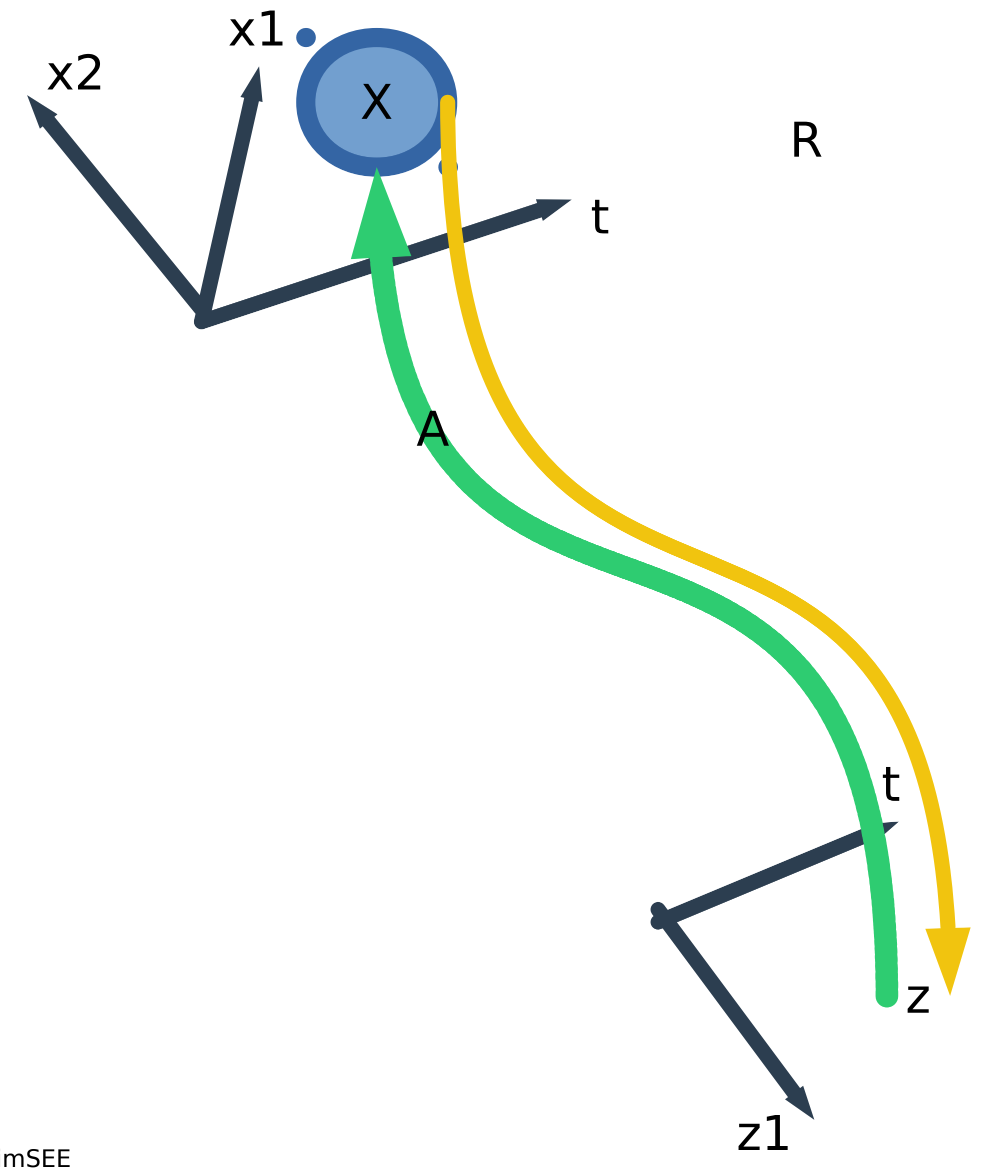
The CEGH models give us the opportunity to define maps of linear reductions of the state space of the system.

But still, the definition of this mapping is an art based on the knowledge of the operator.

We must choose very carefully what to ignore.

The Stochastic Dual Dynamic Programming (SDDP) used in Brasil's tools is a elegant and power weapon to fight again the Bellman's curse.

Reducción del Espacio de Estado



$$z = R(X)$$

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

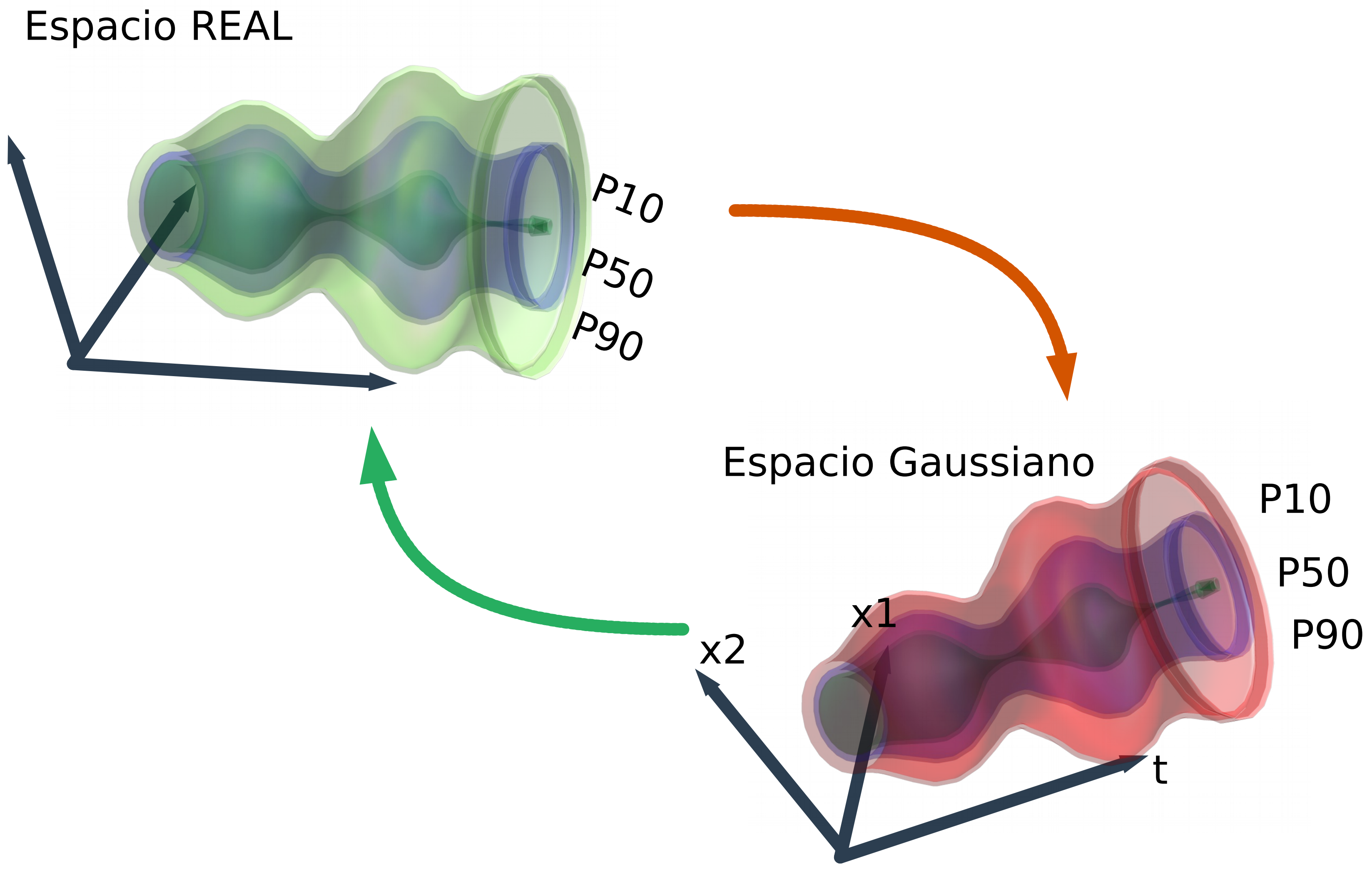
$$X = A(z, w)$$

w, ruido que permite poblar el volumen de X que mapea en el z dado.

Operador Sin Pronósticos.

Operador Con Pronósticos.

Tratamiento de un pronóstico en el modelado CEGH. Gausianización.

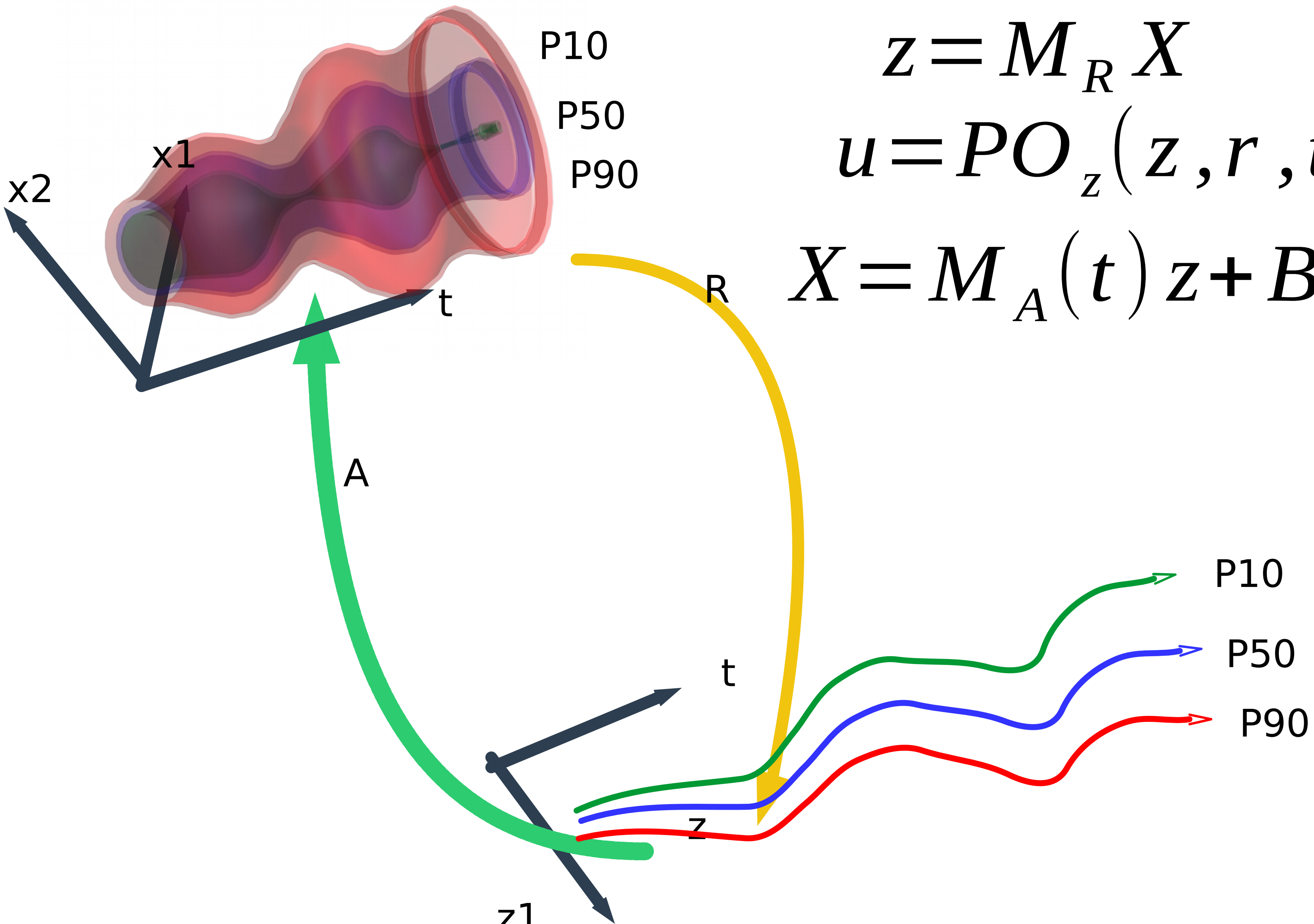


Tratamiento del pronóstico en el espacio Gaussiano con reducción.

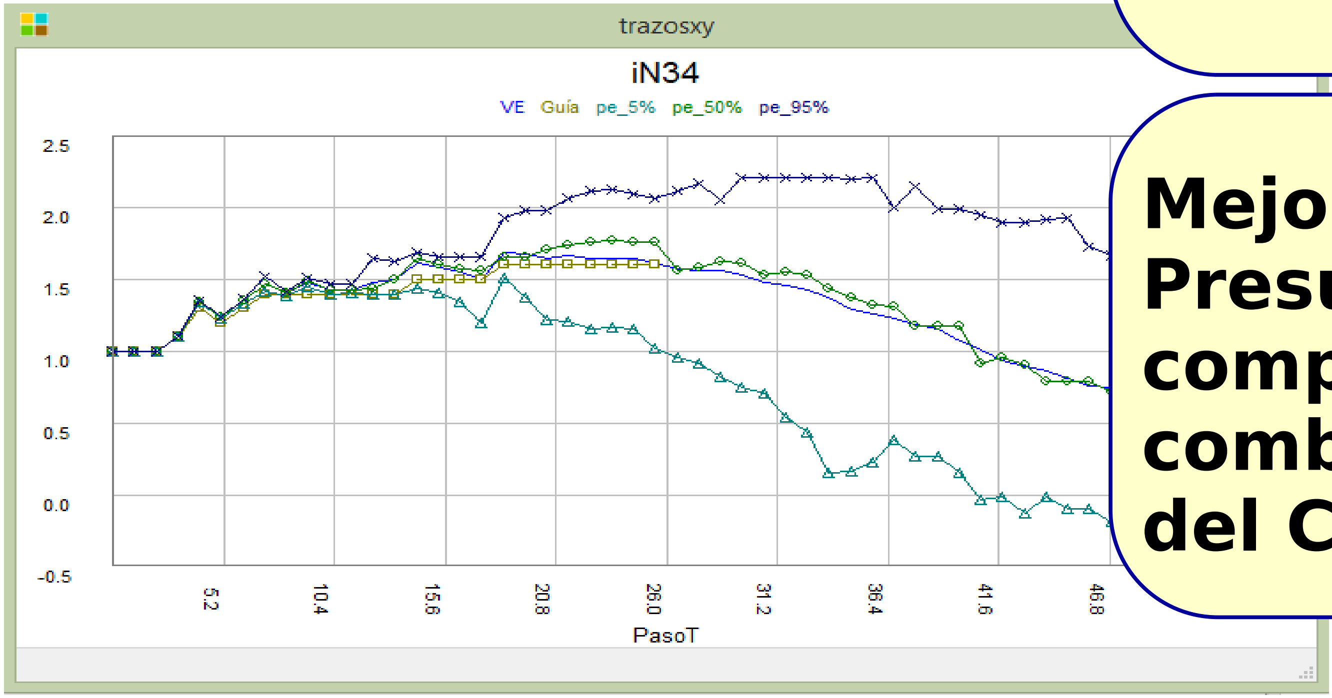
$$z = M_R X$$

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

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



Incorporación de iN34 a la Programación Estacional



Reducción de CAD 5% apróx.

Mejora en Previsión Presupuestal y compras de combustibles 30% del CAD

Encadenamiento de Salas.
De la Planificación al la Operación.

Sala de Largo Plazo Planificación
ej. 40 años, paso semanal, 5 postes
X = (Bonete, H, iN34)

Sala de Largo Plazo Prog.Estacional (ADME)
3 años, paso diario, 5 postes.
X=(VBonete, hRN, hSG, iN34)

Sala de Mediano Plazo (ADME)
OptSim: 1 meses, paso diario, 5 postes
engancha con CF estacional.
X=(VBonete, VPalmar, VSG, hRN, hSG, iN34)

Sala de Corto Plazo Prog.Semanal (ADME)
OptSim: 14 dias, paso horario, 1 poste
X=(VBonete, VPalmar, VSG)

Encadenamiento de Salas.
De la Planificación al la Operación.

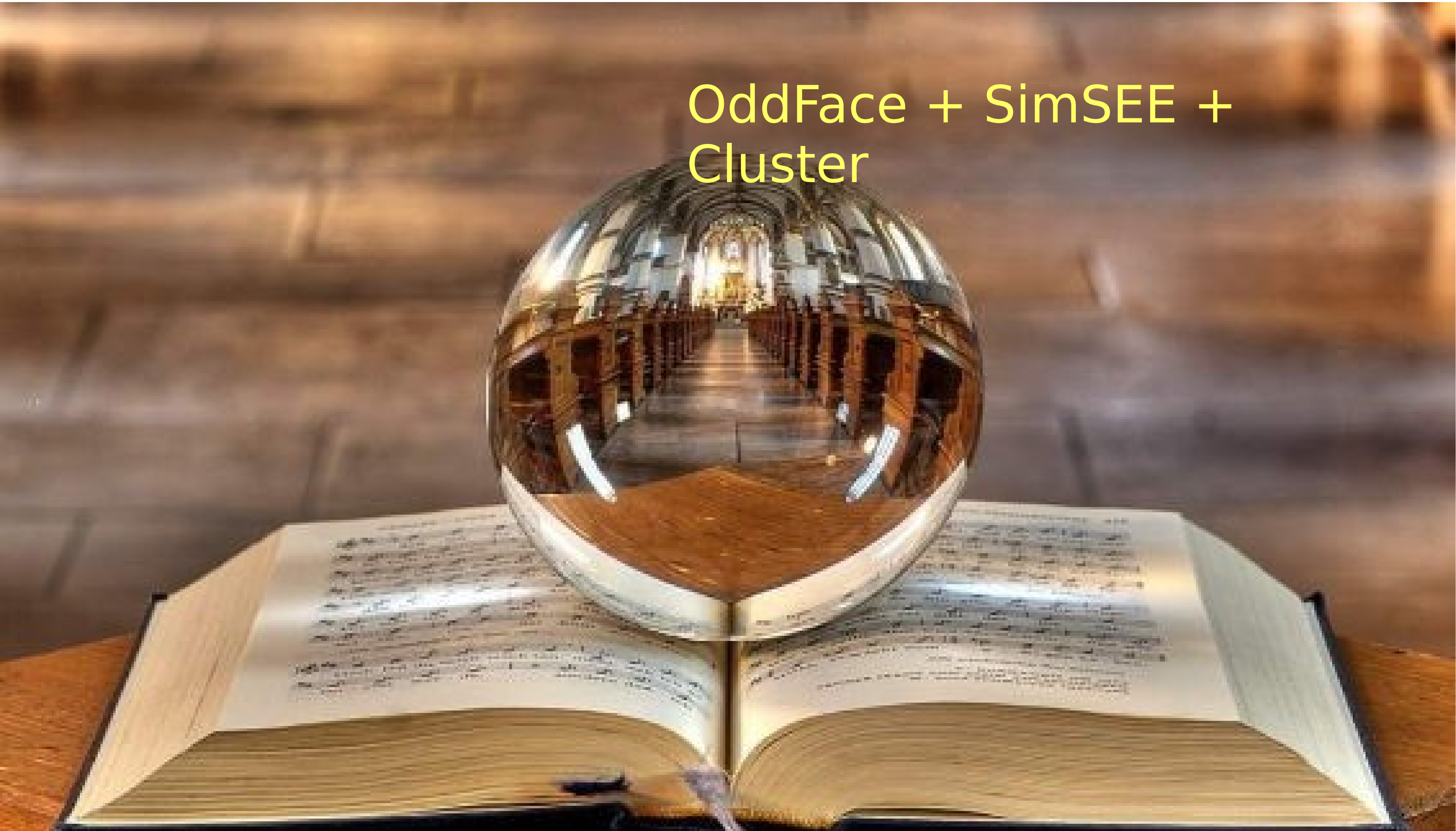
CF(Bonete, H, iN34, kPaso)
Sala de planficación.

CF(VBonete, hRN, hSG, iN34, kPaso)
Sala LP-ADME *Programación Estacional*

CF(VBonete, VPalmar, VSG, hRN, hSG, iN34, kPaso)
Sala MP-ADME

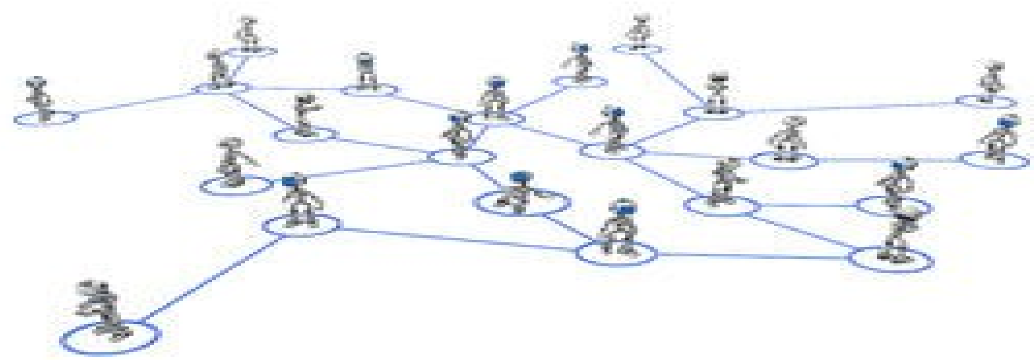
CF(VBonete, VPalmar, VSG, kPaso)
Sala CP-ADME
Programación Semanal y Diaria.

Optimización del plan de inversiones.
¿Qué, cuándo y cuanto?.
Hipótesis inciertas = grandes riesgos.



Optimizador del plan de inversiones en generación. OddFace + PIG.

(2010)



Optimizador distribuido de funciones de alto costo de evaluación.

Algoritmos genéticos.
Uso de redes de cómputo.

Intermitentes, Costo de Falla y Riesgo.

Alternativas para expansión de la generación

	USD/MWh	USD/MWh					
	CF	**CV(*)**			**MW**	**MUSD**	**meses**
Turbina aeroderivativa	15	150			60	71	18
Ciclo combinado	25	100			180	355	30
Centrales a Carbón	45	80					36
Centrales Nucleares	??						??
Moto-generadores	18	120					20
Eólica	50	0			50	197	18
Solar	50	0			50	197	12
Biomasa	65	50			20	102	30
Hidroeléctrica	40	0					60

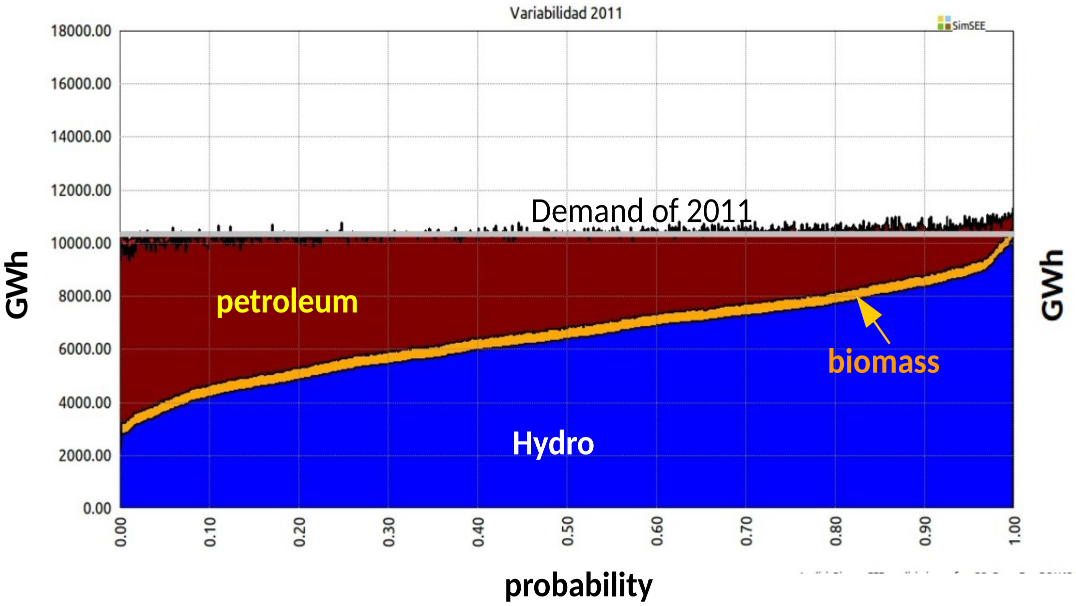
CV(*) @petróleo a 70 USD/bbl

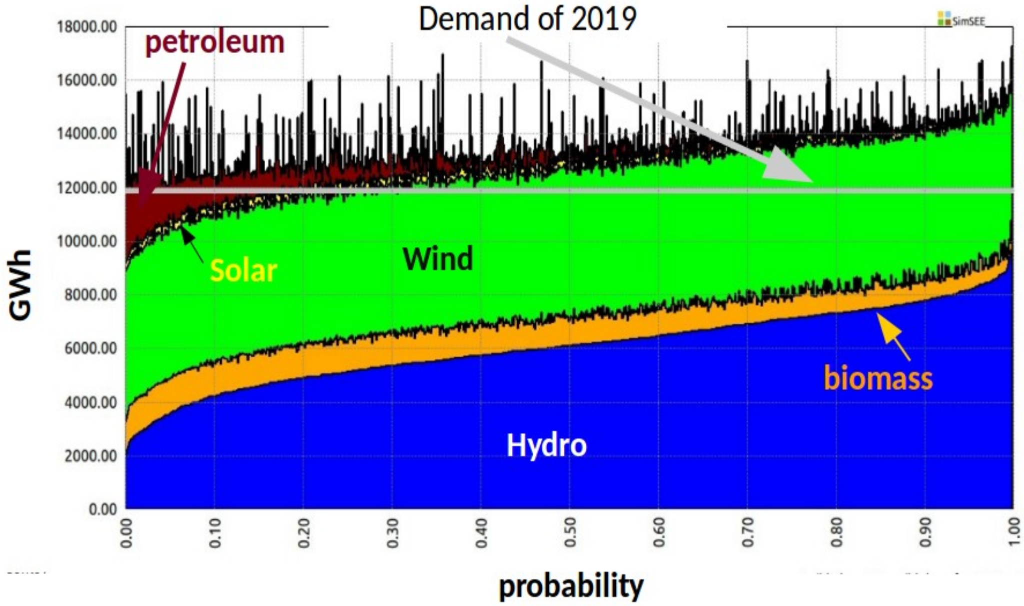
Costos Fijos

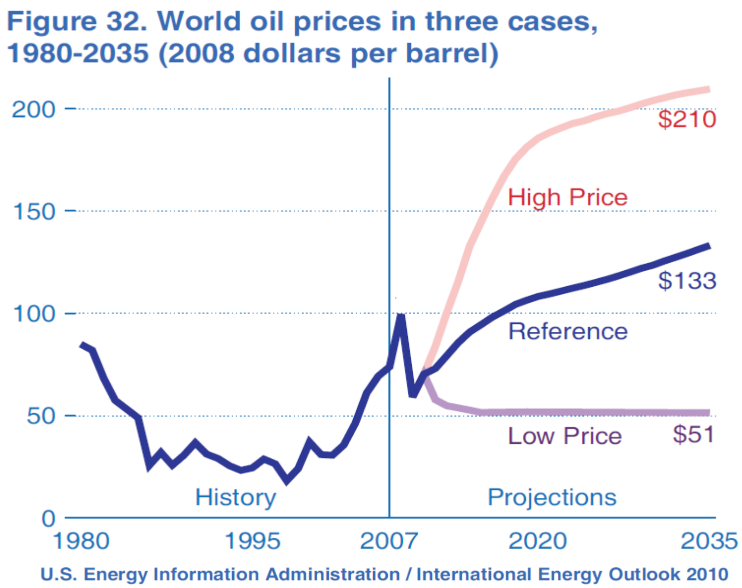
Costos Variables

Período de construcción

What we have done in Uruguay. (2010-2018)

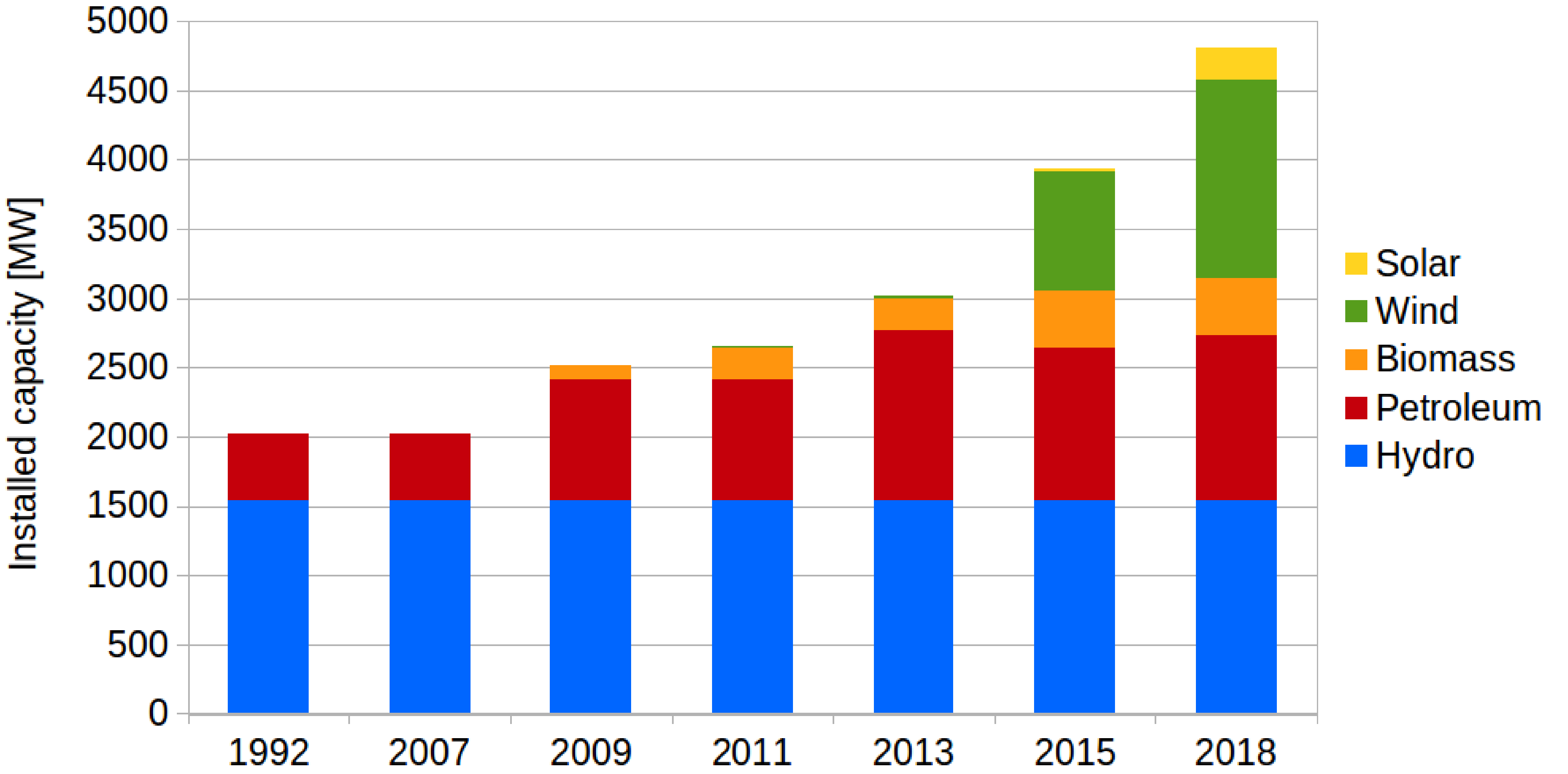




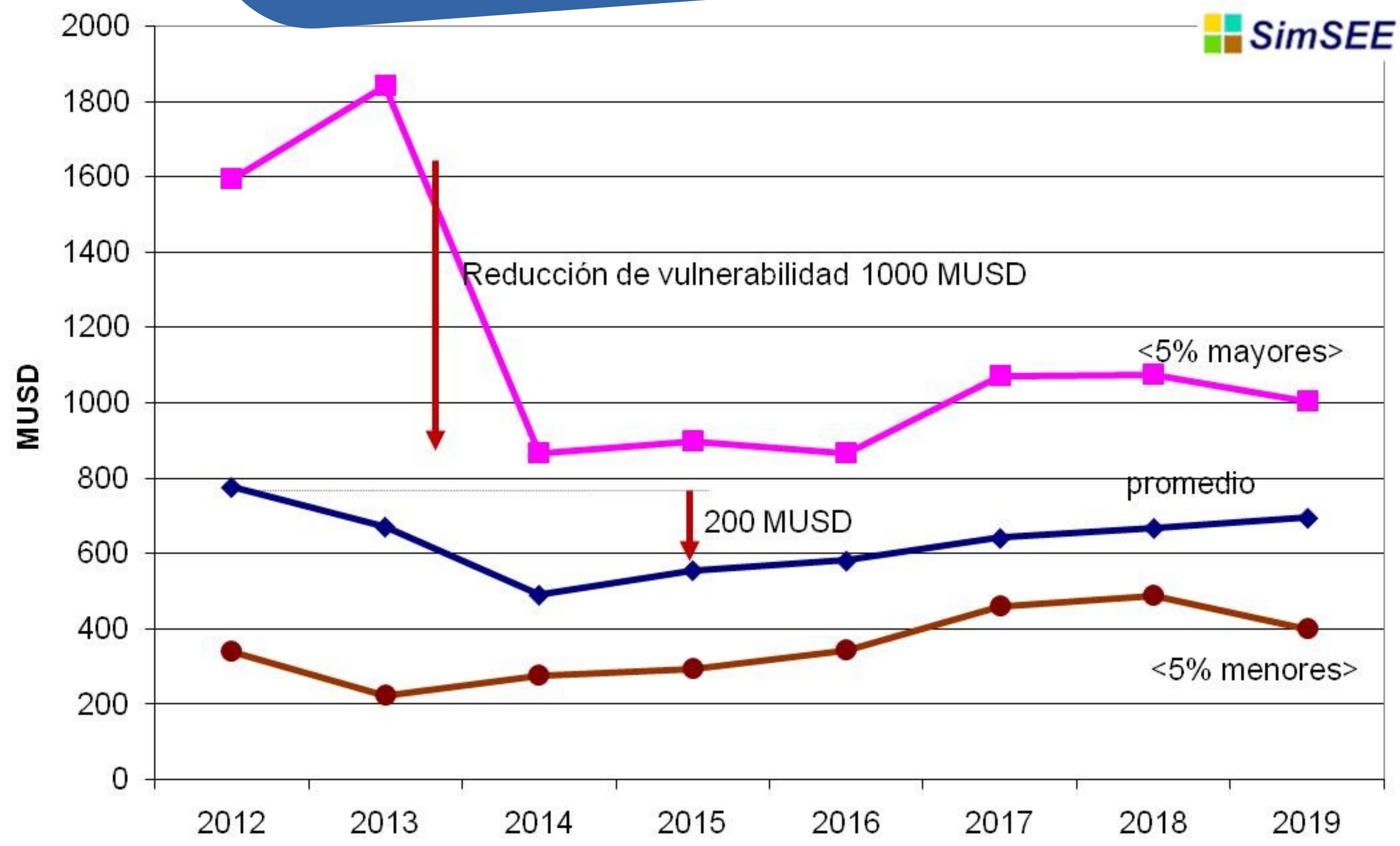


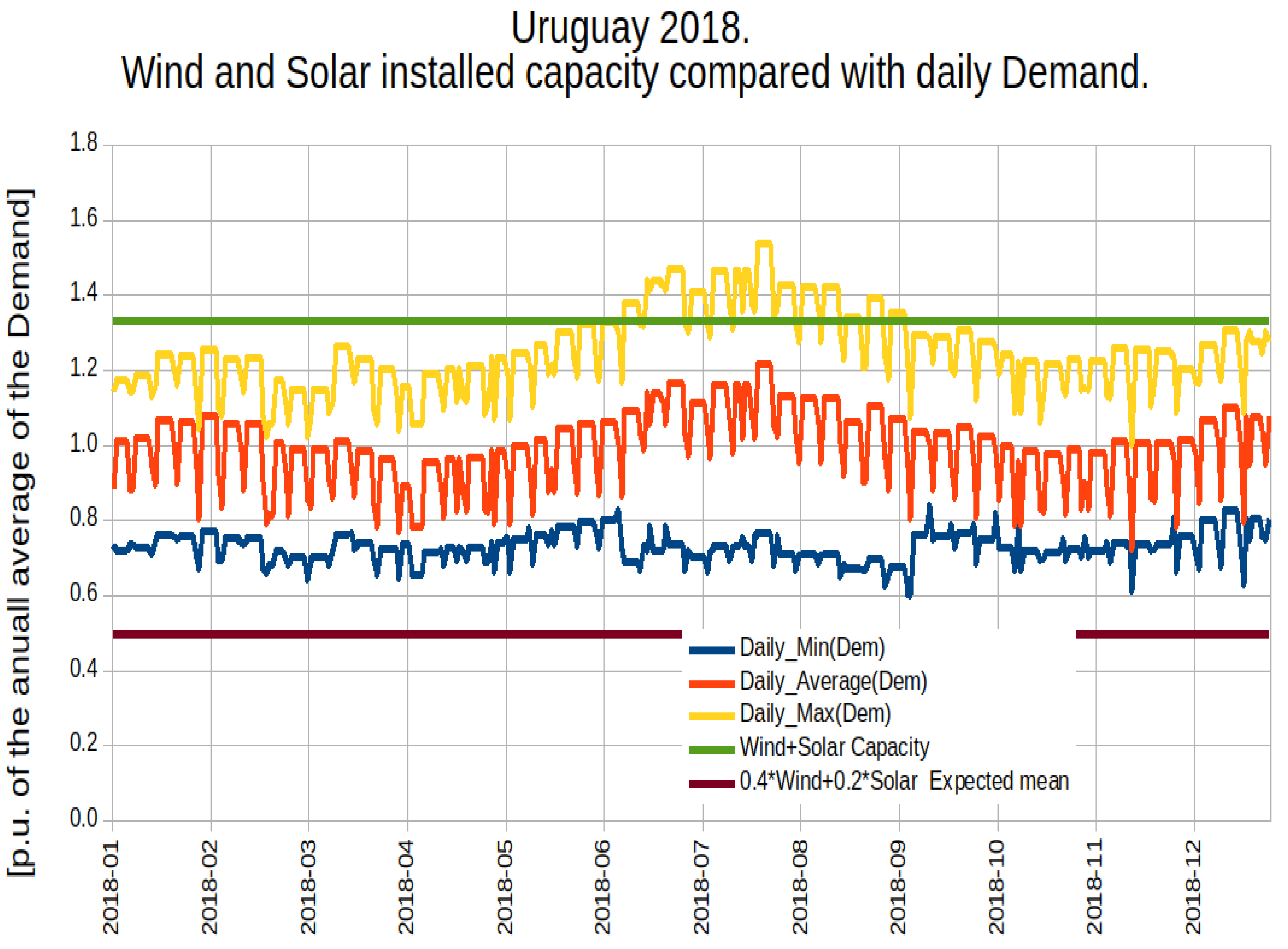
Source: The risk images are from the IIE studies carried out in 2010 and 2018 respectively.

Actual installed capacity.



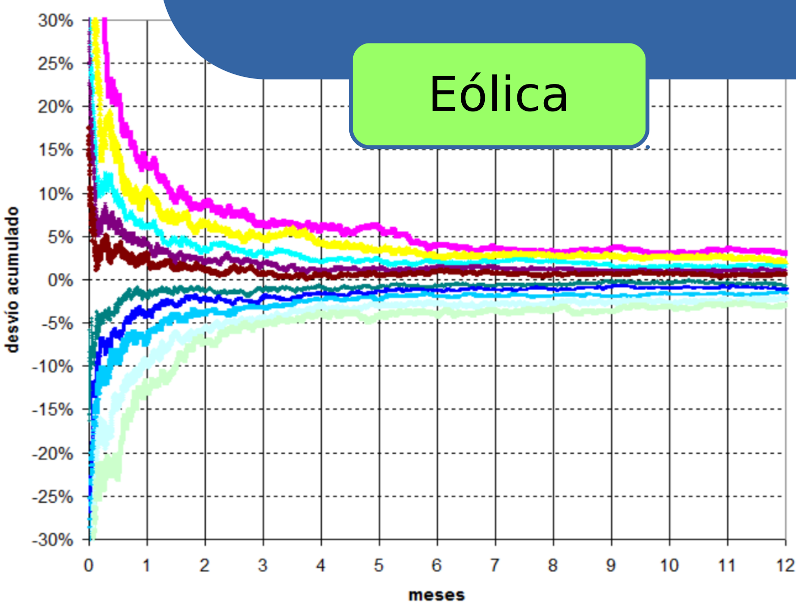
CAD - Generación

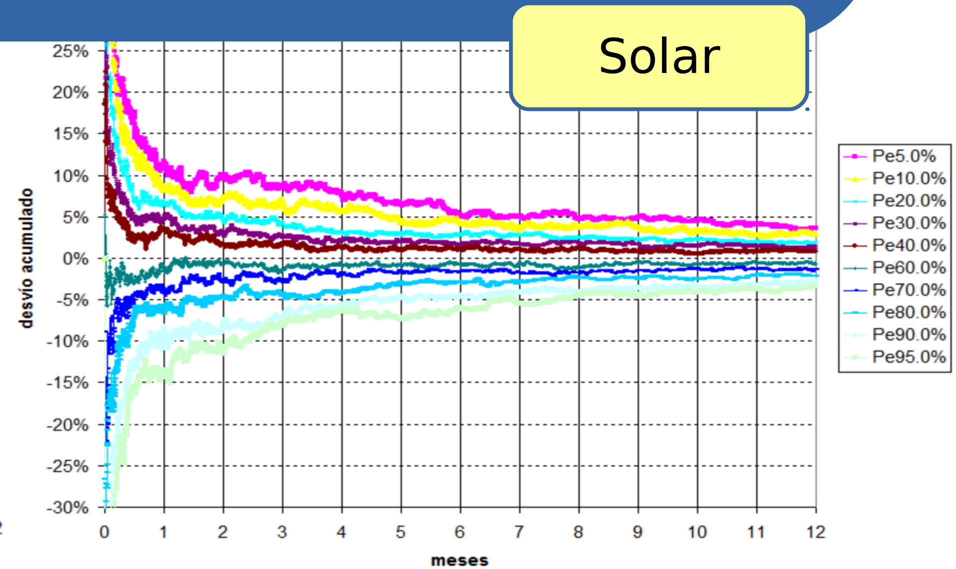


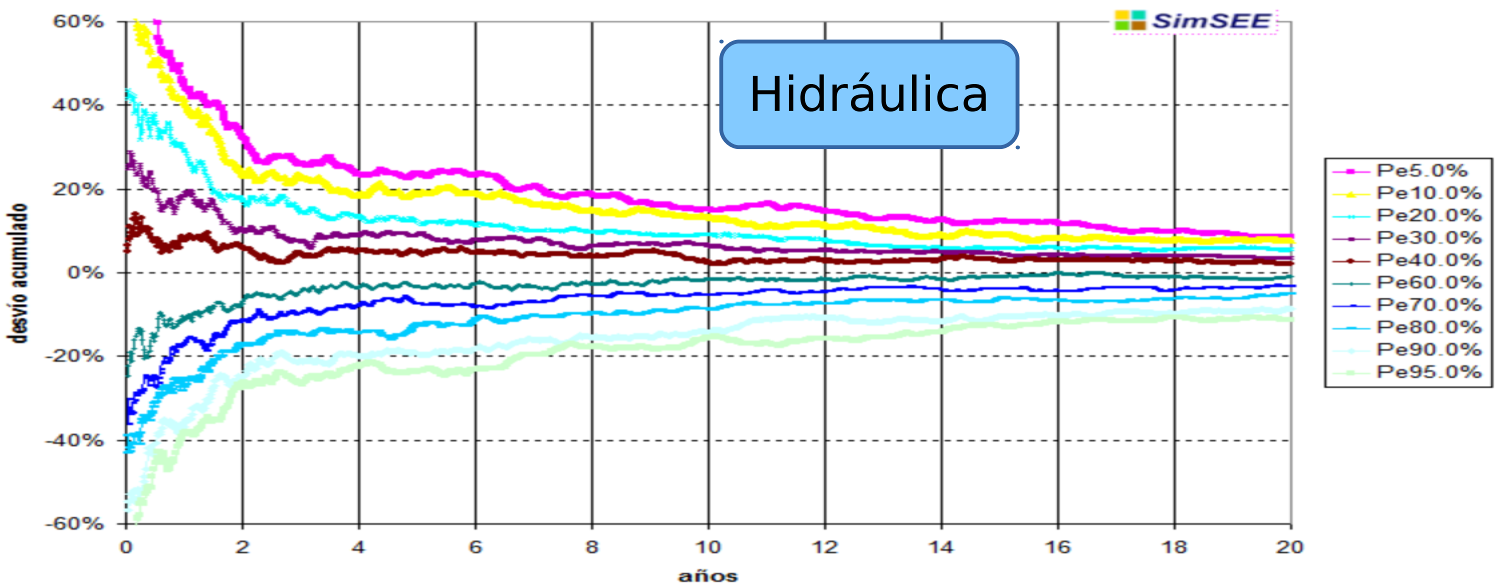


Uruguay 2018.
Wind and Solar installed capacity compared with daily Demand.
[p.u. of the anuall average of the Demand]
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
2018-01
2018-02
2018-03
2018-04
2018-05
2018-06
2018-07
2018-08
2018-09
2018-10
2018-11
2018-12
Daily_Min(Dem)
Daily_Average(Dem)
Daily_Max(Dem)
Wind+Solar Capacity
0.4*Wind+0.2*Solar Expected mean

Conos de confianza 90% del desvío del valor esperado.
(estudios 2014)







Frequency of the Wind, Solar and Hydro variability. (Uruguay).

Solar

Wind

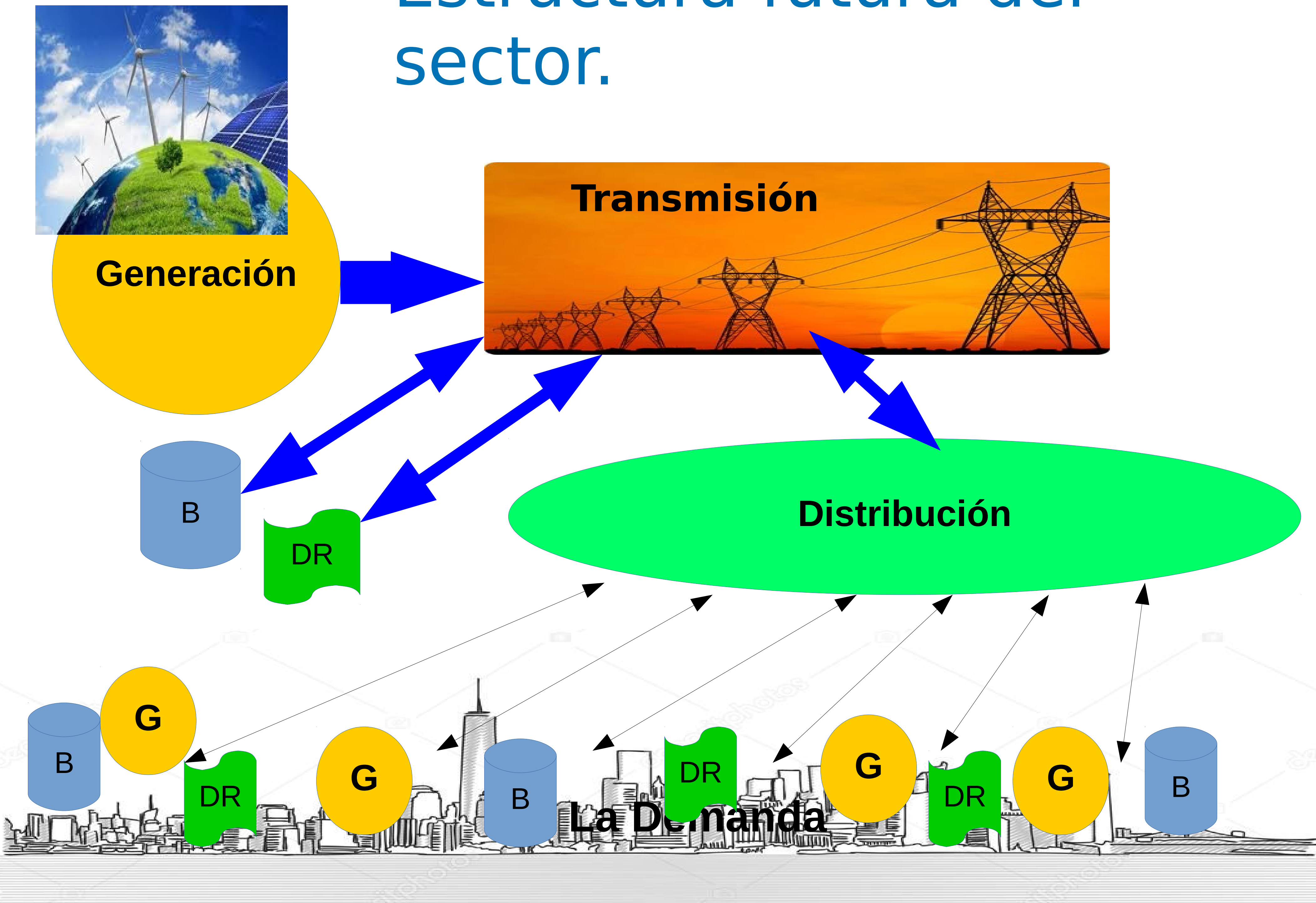
For wind and solar energy, averagin **2 months**, the energy received will in an interval of 10% of its expected value with a 90% confidence.

Hydro

For hydro, to reach an interval of 10% of the expected value width a 90% confidence we need to average **16 years**.

Pronósticos de corto plazo, pueden mejorar capacidad de filtrado de ERNC.

Estructura futura del sector.




Variabilidad


Realidad 2016

PRONOS

The PRONOS project allowed us to develop the models of the wind and solar generation plant installed in the national territory.
In real time we receive instantaneous information about the meteorological variables of each location together with the generation and availability information of each plant.

Twice a day we receive forecasts from Meteoblue with weather forecasts for the next ten days with hourly detail.

https://pronos.adme.com.uy

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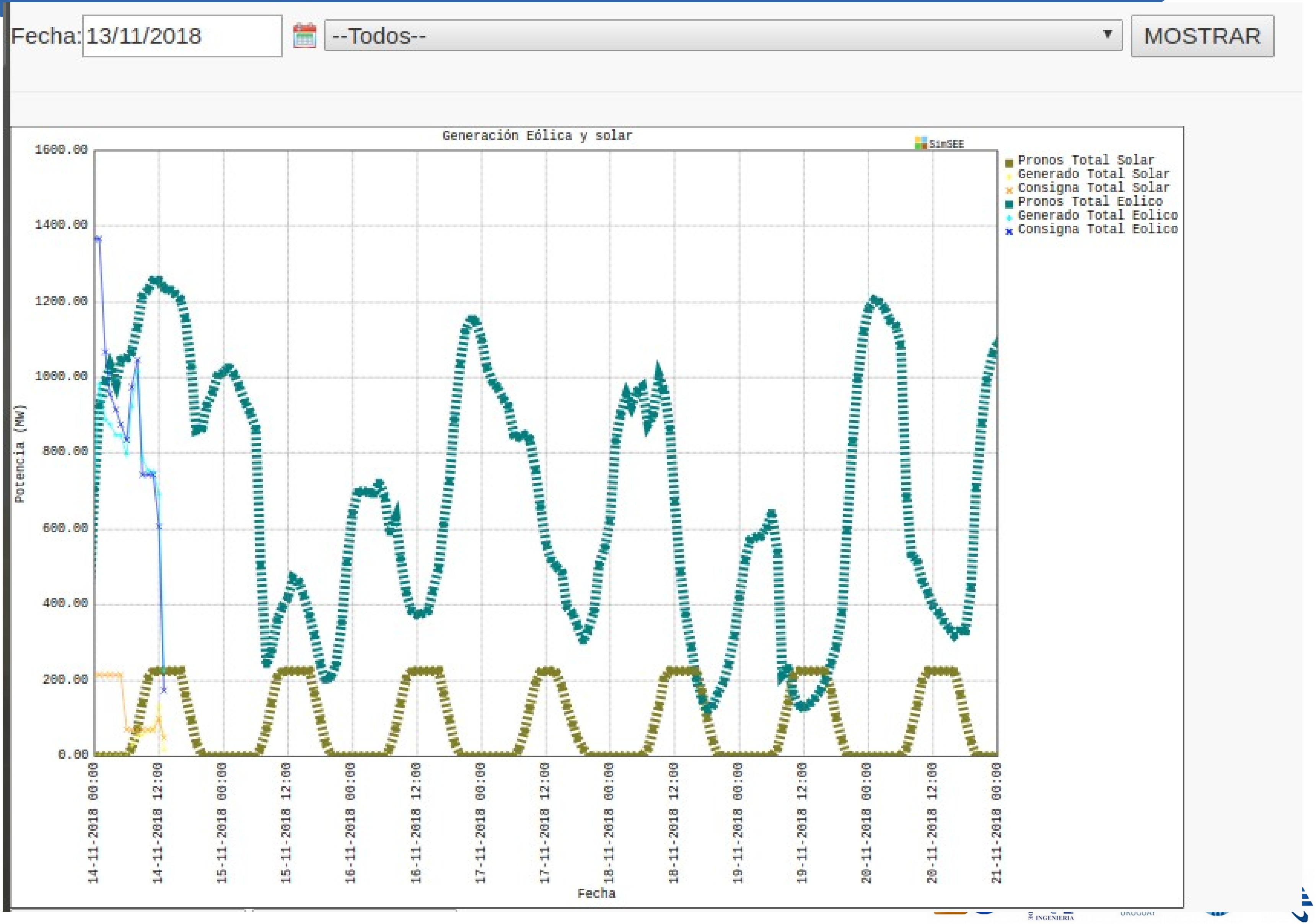
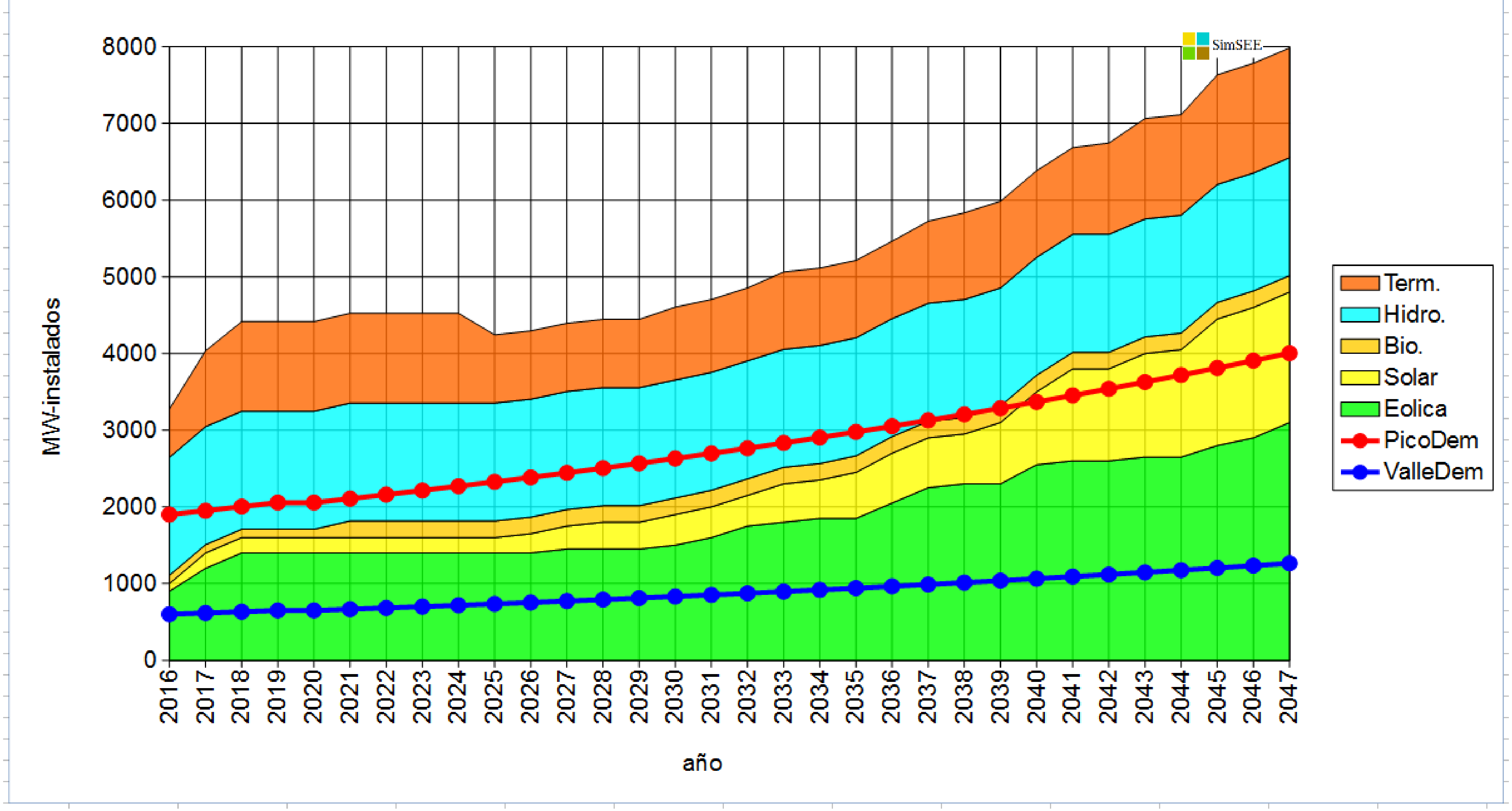
Pronósticos de generación

http://pronos.adme.com.uy/svg/



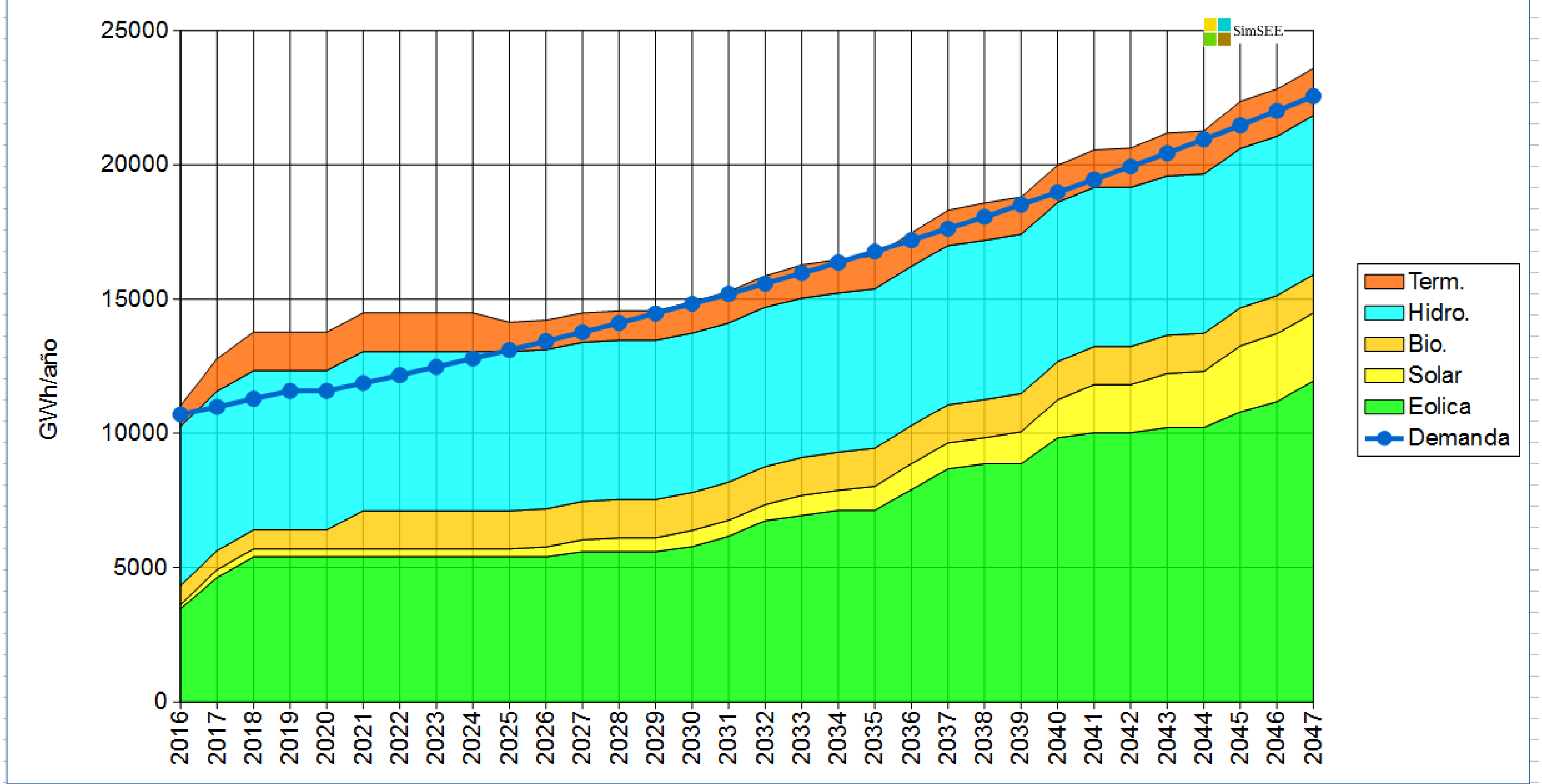
Fuente: Plan óptimo 2016-2046. Marzo 2016 Depto. Potencia IIE-FING.

Capacidad instalada por fuente. Uruguay 2016-2046



Fuente: Plan óptimo 2016-2046. Marzo 2016 Depto. Potencia IIE-FING.

Generación esperada por fuente. Uruguay 2016-2046




The optimal expansion generates an energy surplus.

VATES

Forecast of the next 336 hours of the power system operation.

VATES is running in an infinite loop at ADME.
At each hour, assimilating the forecasts and the real system's a SimSEE simulation is performed given the forecast of the optimal dispatch of the system for the next days with a hourly detail.

Main results: **(update every hour)**
1) Forecast information about the probabilistic dispatch of thermal units.
2) Generation of a price signal as the basis for allowing future National Responsive Demands.
3) Determination of energy packets available for export a week ahead.

https://vates.adme.com.uy

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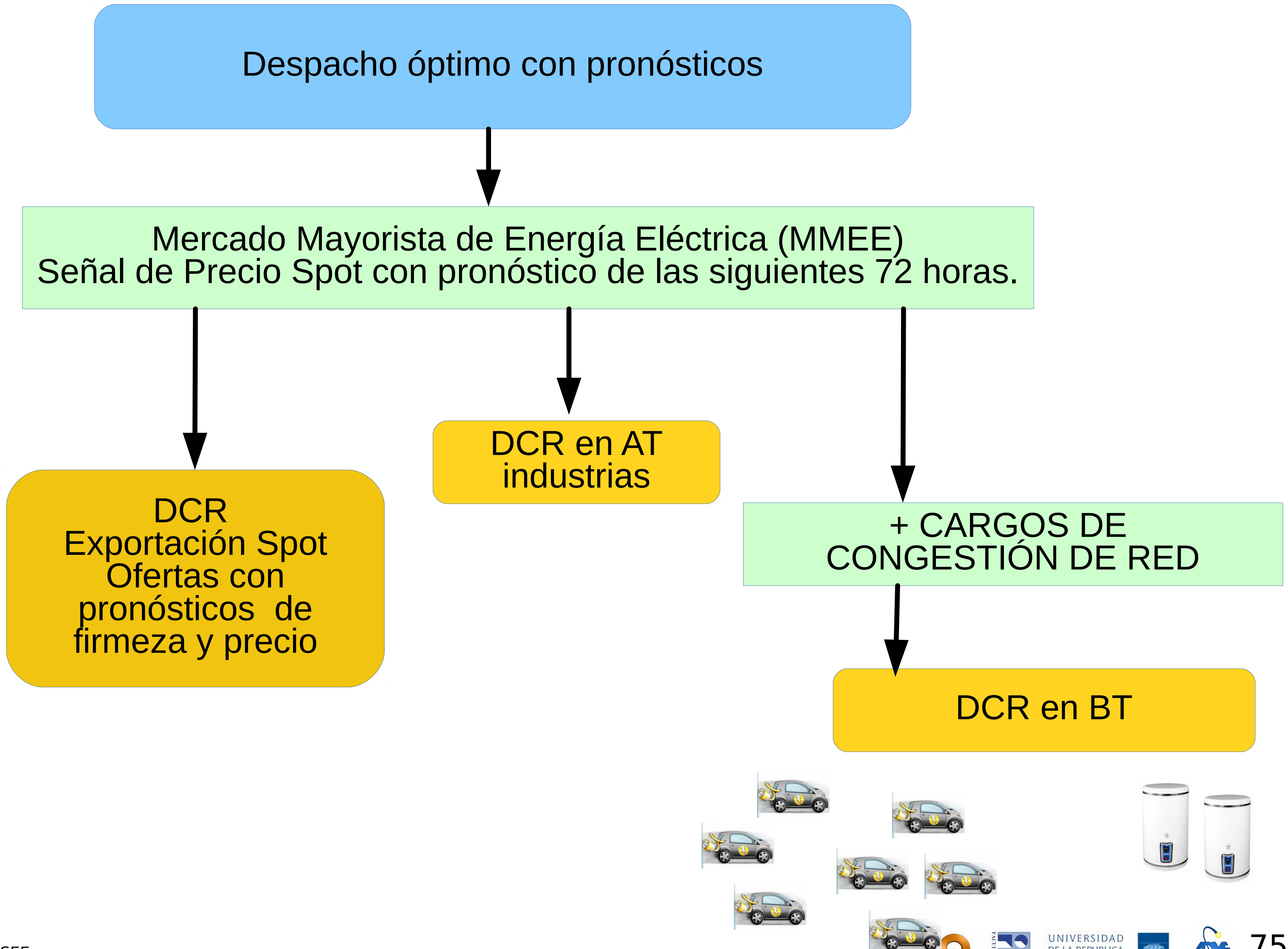
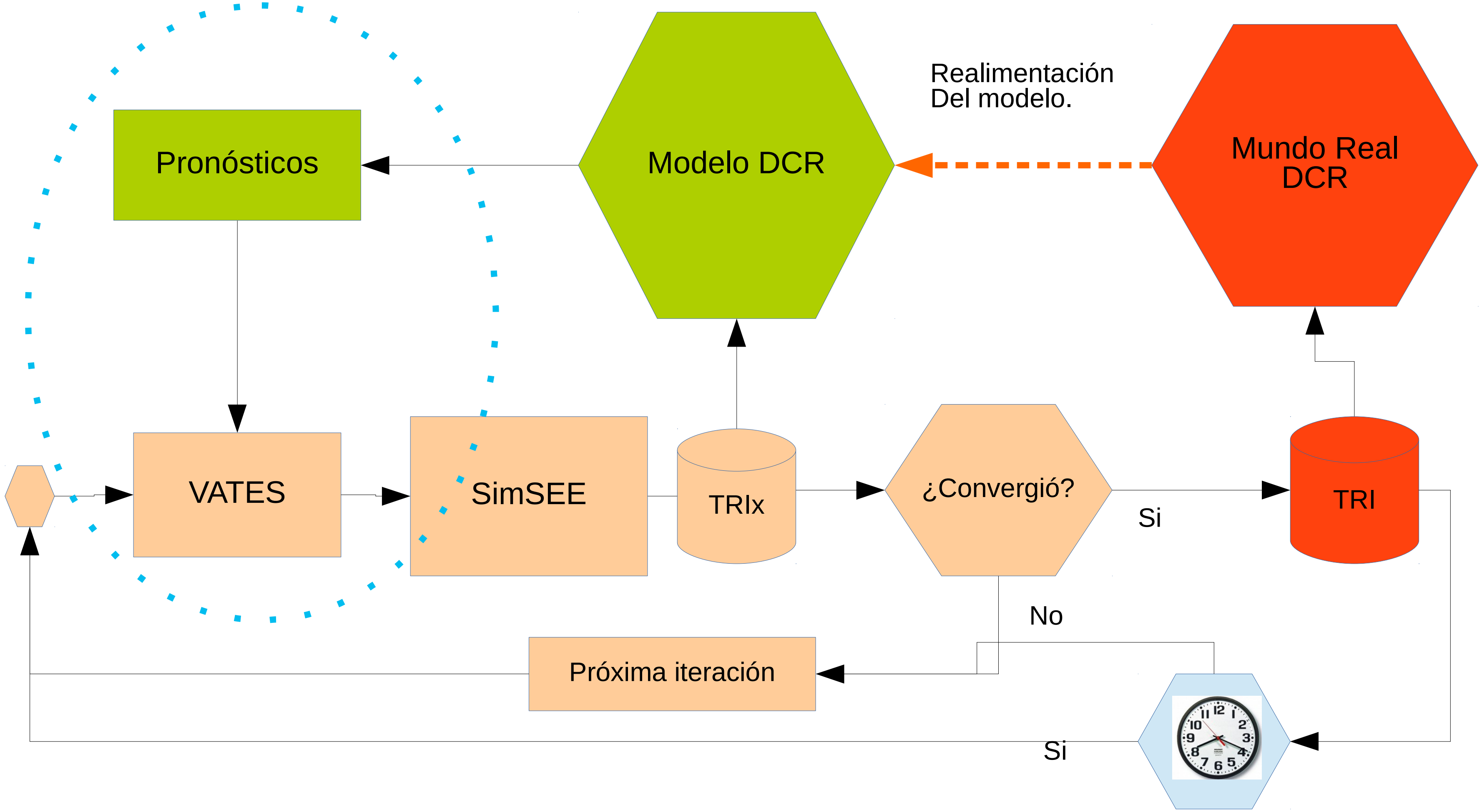
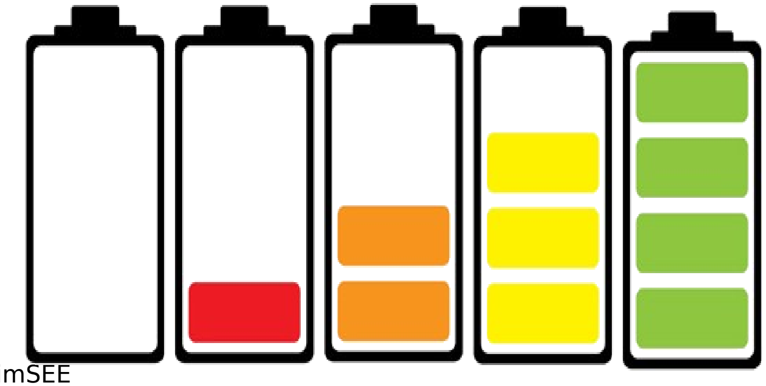

Despacho óptimo con pronósticos
Mercado Mayorista de Energía Eléctrica (MMEE)
Señal de Precio Spot con pronóstico de las siguientes 72 horas.
DCR en AT
industrias
DCR
Exportación Spot
Ofertas con
pronósticos de
firmeza y precio
+ CARGOS DE
CONGESTIÓN DE RED
DCR en BT

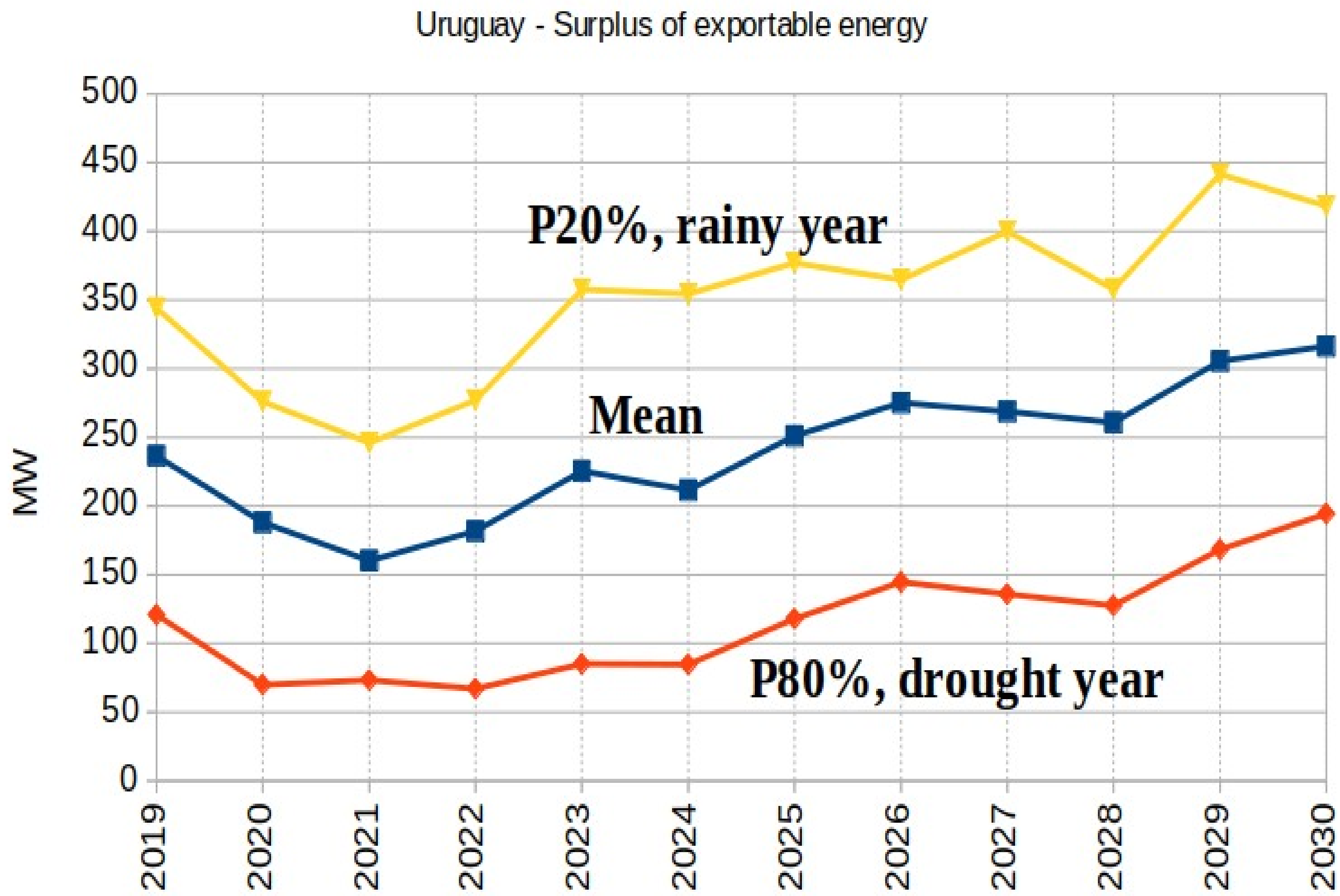


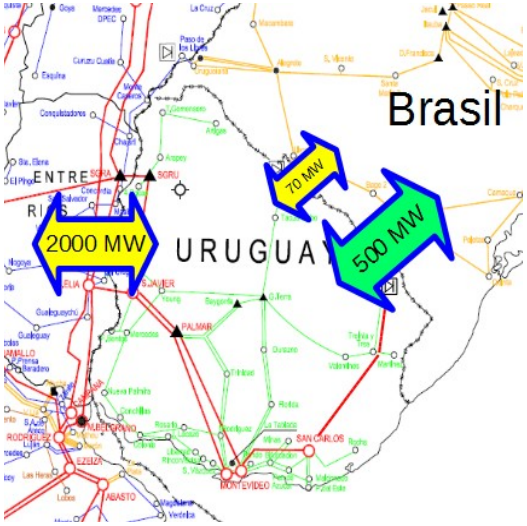
Realimentación
Del modelo.
Pronósticos
Modelo DCR
Mundo Real
DCR
VATES
SimSEE
TRIx
¿Convergió?
Si
TRI
No
Próxima iteración
Si

Responsive Demands and Battery Storage are the key to filter intra week energy availability variations.



The regional integration id the key to filter slow variations.





Where we are?.

We have demonstrated the need to reduce the time step of the simulation to 1 hour and how the dimension of the state space of the system grows when a fast dynamic has to be represented.

It showed mechanisms designed to allow specifying reductions in the representation of state space in an attempt to fight against the curse of Bellman's dimensionality.

What we are working on now for the future.

We are currently working on adding learning mechanisms to the SimSEE platform so that the tool can learn from the repeated simulations of the same system and be able to make reductions in the state space that means less loss of information in the representation. of the optimal operation policy.

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.