IEEE T&D PES Conference and Exposition LATIN AMERICA 2020

Optimal Energy Dispatch of Power Systems with high integration of Variable Renewable Energies.

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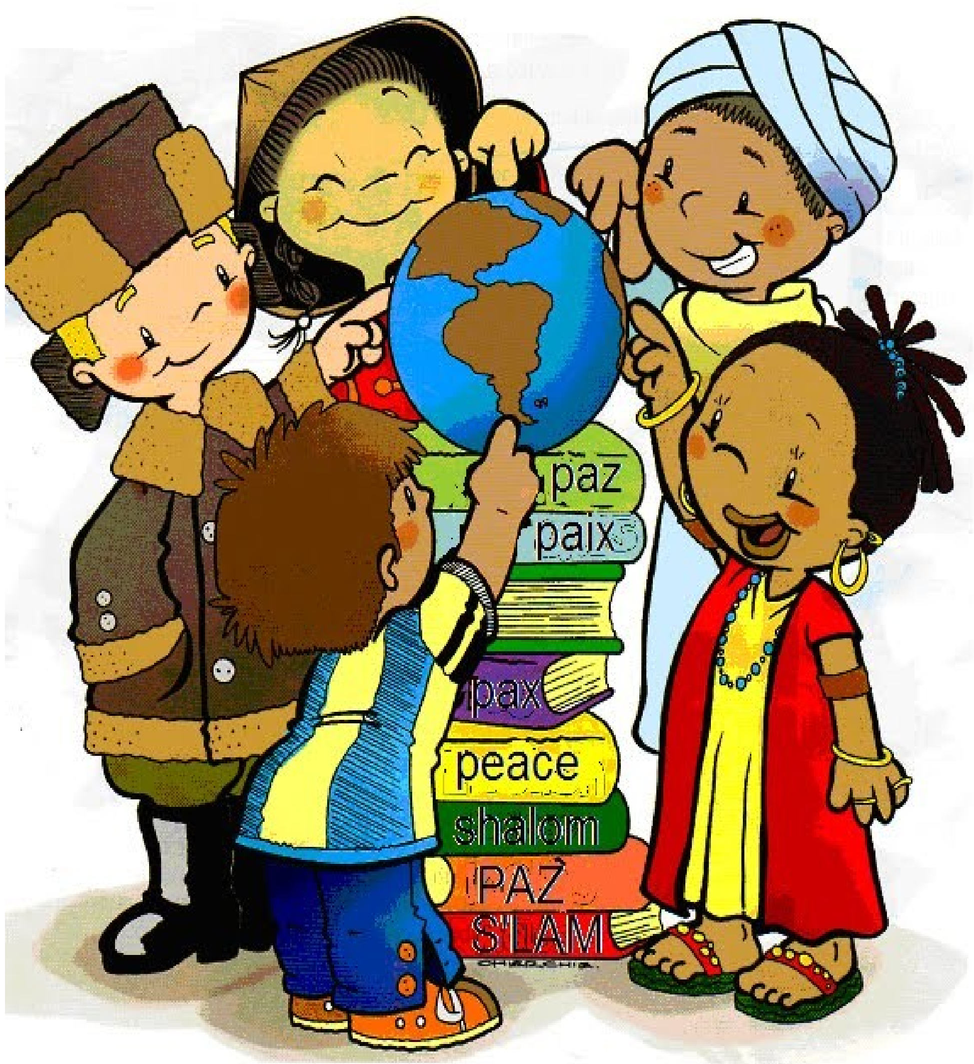
Uruguay - September *2020*

SimSEE

- This tutorial is about the optimal operation of power systems with high variability in their resources.
- We will see the tools developed for modeling such variabilities and for the assimilation of their forecasts.



Each system has its peculiarities.

The optimal solution is surely different for each country.

Characterization of the variability in Uruguay.

A measure of the difficulty of handling a variability energy resource is the averaging-time needed to obtain the expected value with a 10% error with 90% confidence.

water inflows

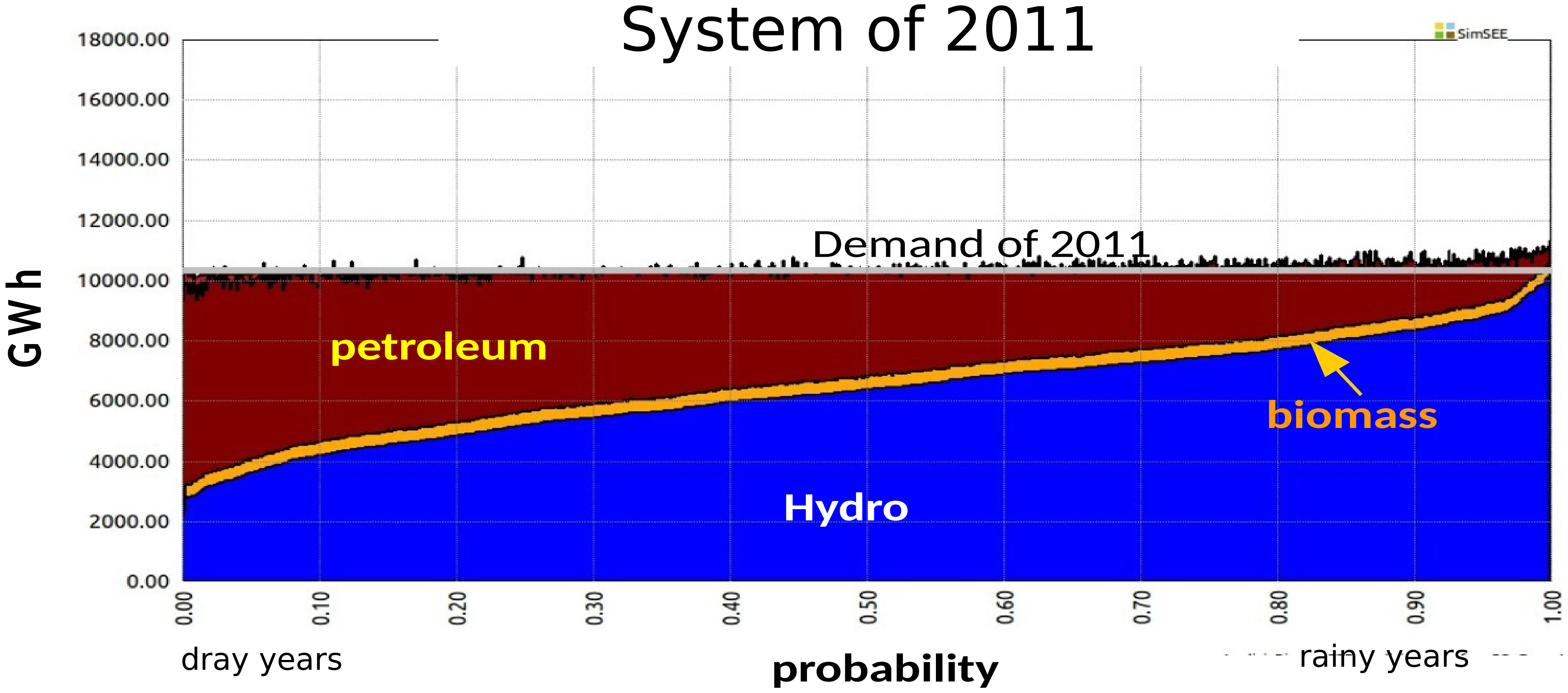
16 years

wind & solar

WS

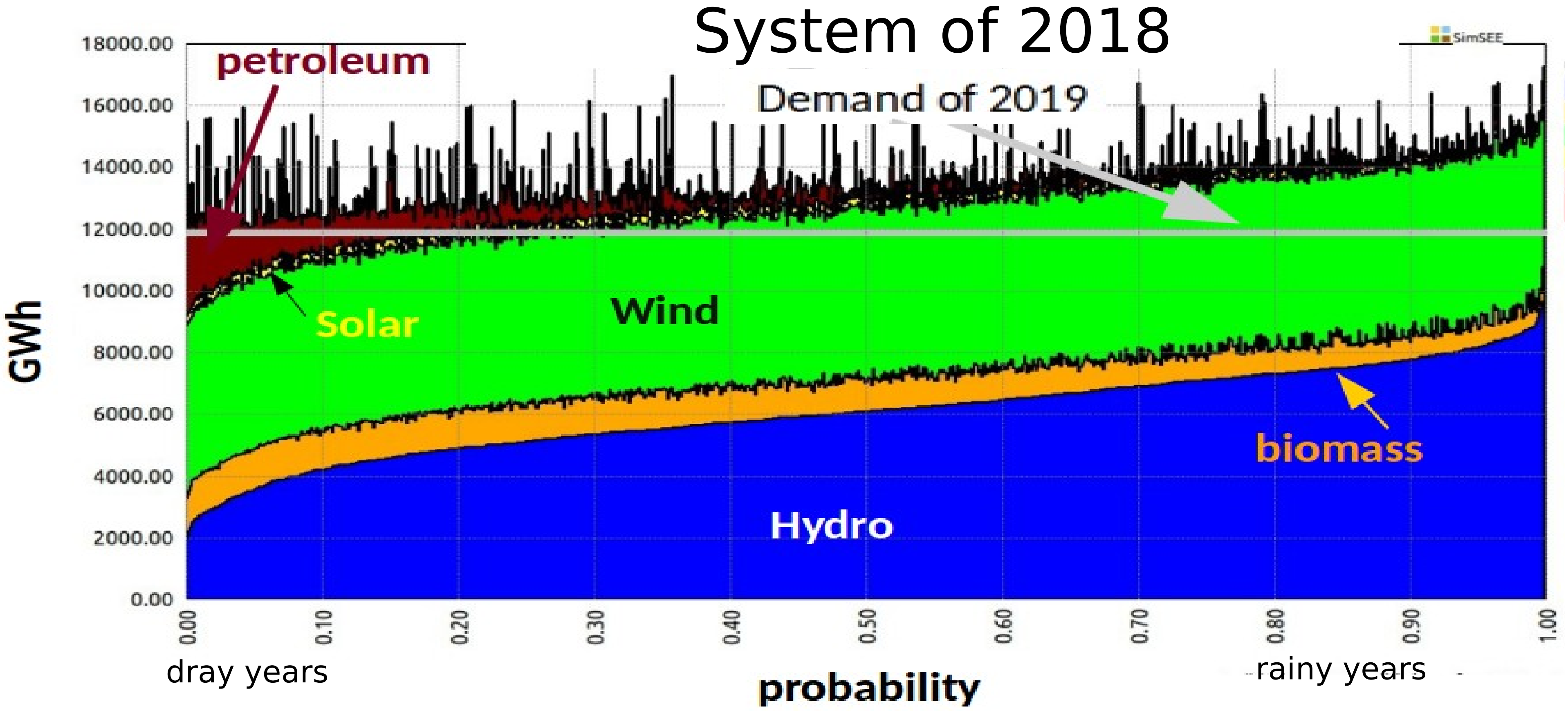
2 months

Changes in the energy matrix of Uruguay



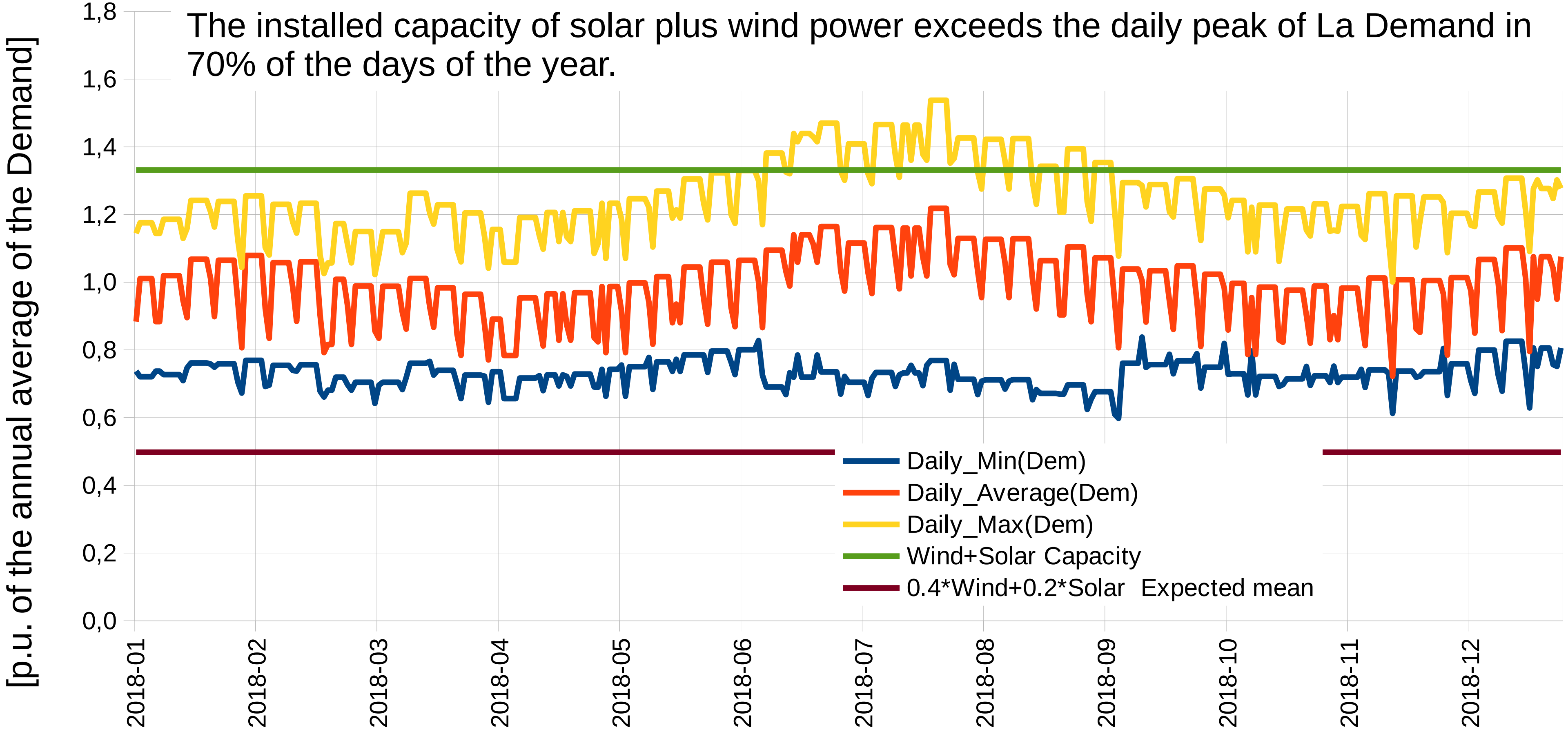
Source: The risk images are from the IIE studies carried out in 2010 and 2018 respectively.

Changes in the energy matrix of Uruguay



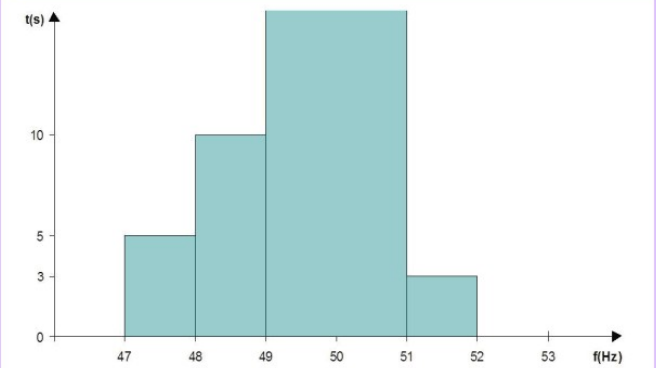
Source: The risk images are from the IIE studies carried out in 2010 and 2018 respectively.

Uruguay :
Wind and Solar installed capacity compared with daily Demand.



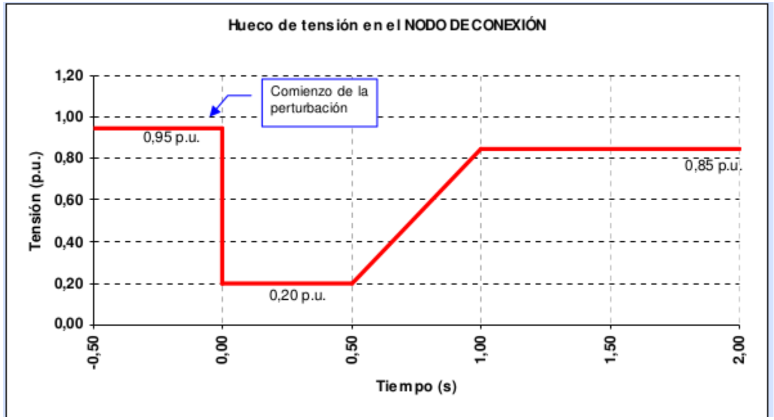
Network Codes.

(B)



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

Figura 1



(A)
Cada unidad generadora de energía eléctrica debe como mínimo poder absorber o inyectar en barras de máquina una potencia reactiva de ±15% de su potencia activa nominal, a tensión nominal en dichas barras.

(B)
Las unidades generadoras deben como mínimo poder absorber o inyectar potencia reactiva en función de la potencia activa generada de acuerdo a la curva P,Q de la Figura 3.

Cuando la potencia activa generada sea menor al 10 % de la potencia nominal de la unidad generadora, no se exige una capacidad mínima de absorción o inyección de reactiva.

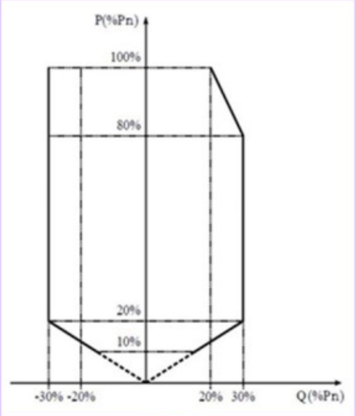
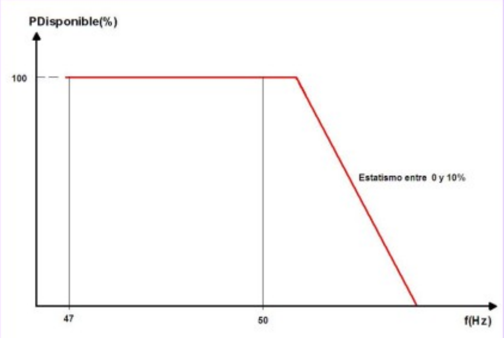


Figura 3

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 debe poder ajustarse entre 1 y 10 % de la potencia nominal de la unidad generadora por segundo.

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



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All generators under control

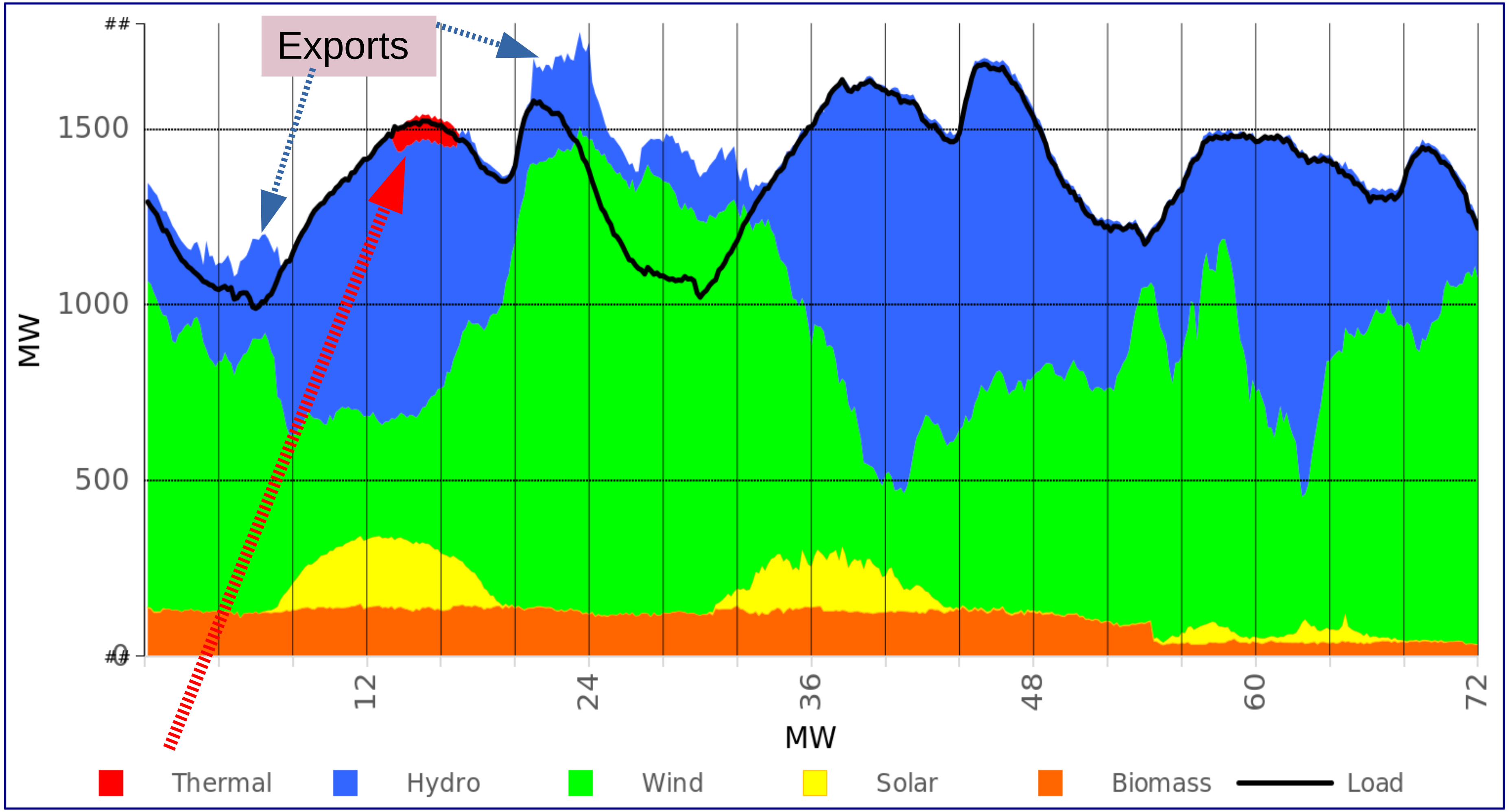
SCADA

Cotrol Modes:
- Active Power Control
- Reactive Power Control
- Voltage Control

Additional tools

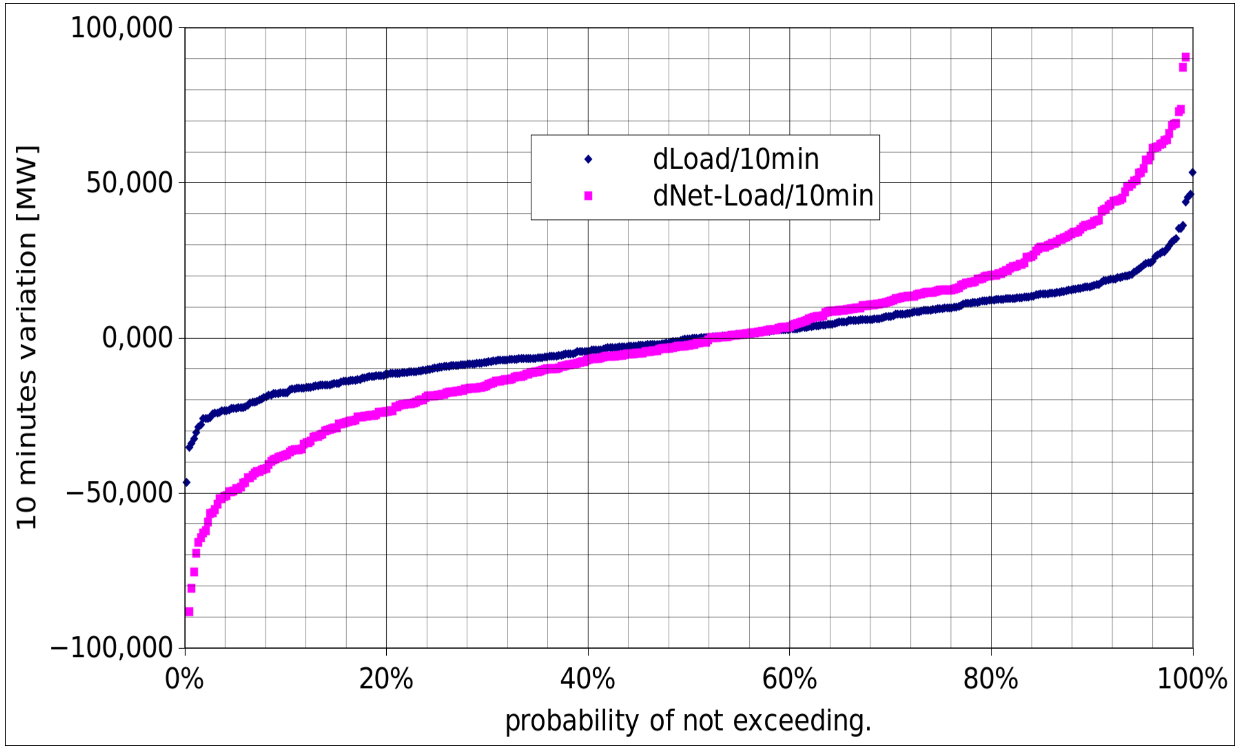
- Authomatic Generation Control (AGC)
- Dynamic Line Rating (DLR)
- Remedial Action Scheme (RAS)

Any 72 hours of January 2020 of the dispatch just as an example



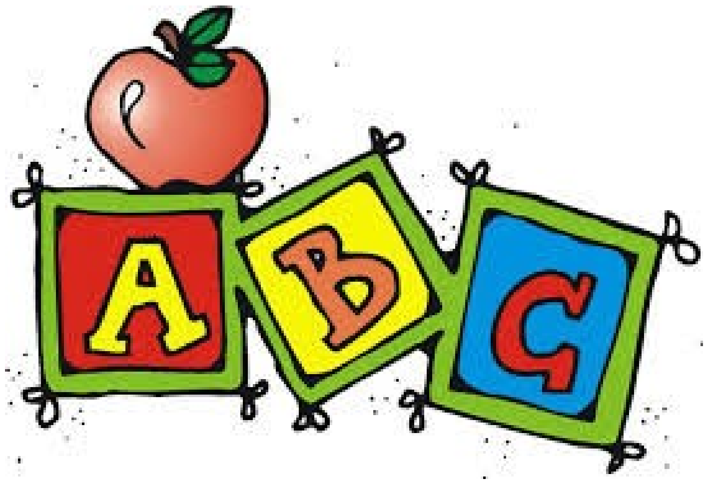
Source: https://adme.com.uy

In the end, it wasn't that difficult. The ten-minute variations of the Net-Demand are only the double of those of the True-Demand.
The Uruguayan system then only needs an additional 25 MW of rotating reserve.



Mission of the System Operator

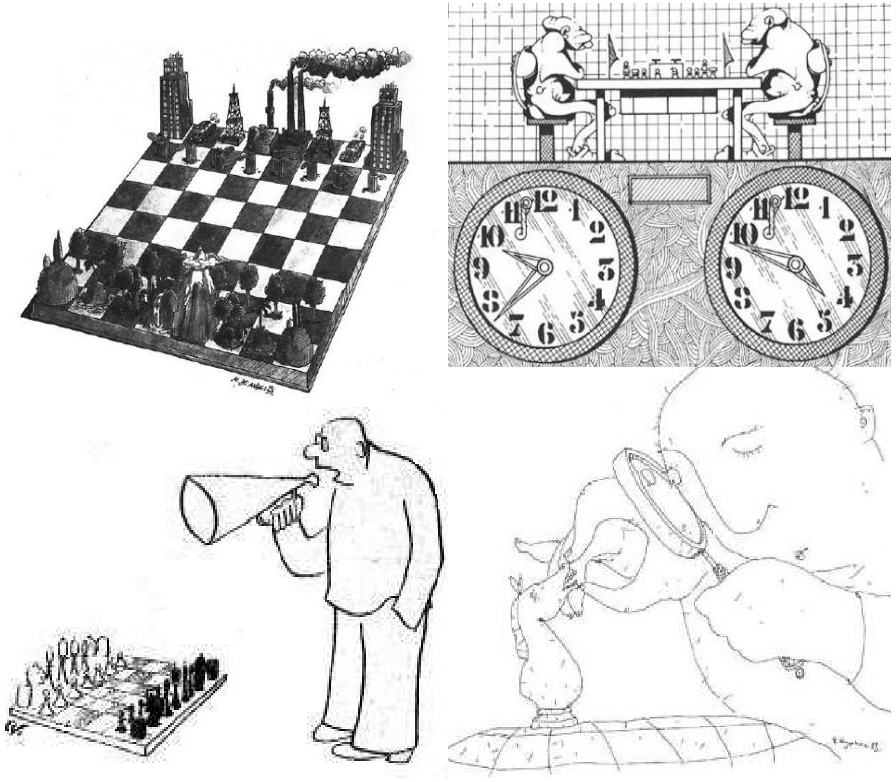
Provide energy with acceptable reliability and quality at the minimum cost.



- Centralized Dispatch.
- Only Variable Costs.
- Contracts are of paper
  (in the sense that they should not interfere in the Dispatch).

SimSEE

https://simsee.org



Platform for simulation of optimal operation of the energy dispatch.

100% OOP

Actors
Playroom
Dynamic parameters
Monitors

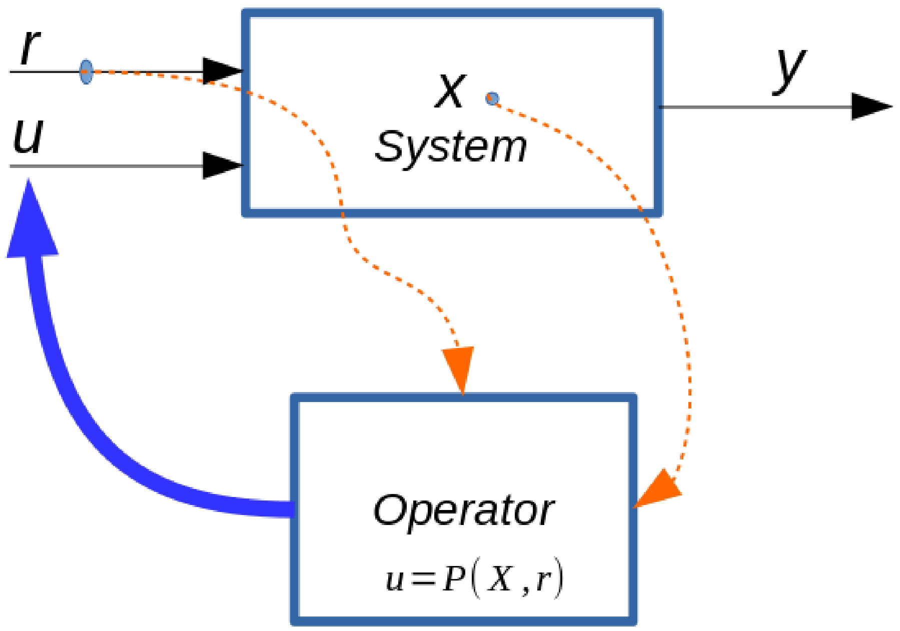
Free & OpenSource

Temporary linking of decisions.

The use of stored resources (water) in the **present** produces an increase in **future** operating costs. The postponement of the use of a stored resource produces an increase in the costs of the present.

The **Optimal Policy** is the one that balances the cost impact between present and future.

The System, The Operator and The Operation Policy



X = State
r = Non-controllable inputs
u = Controllable Inputs

Operation Policy:

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

Instant operating cost:

$$oc(X, r, u, t)$$

Future Cost:

$$FC_P(X_{ahora}) = \langle \int_{now}^{future_{+\infty}} oc(X, r, u, t)\, dt \rangle$$

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

Bellman's curse of dimensionality.

Operation Policy:

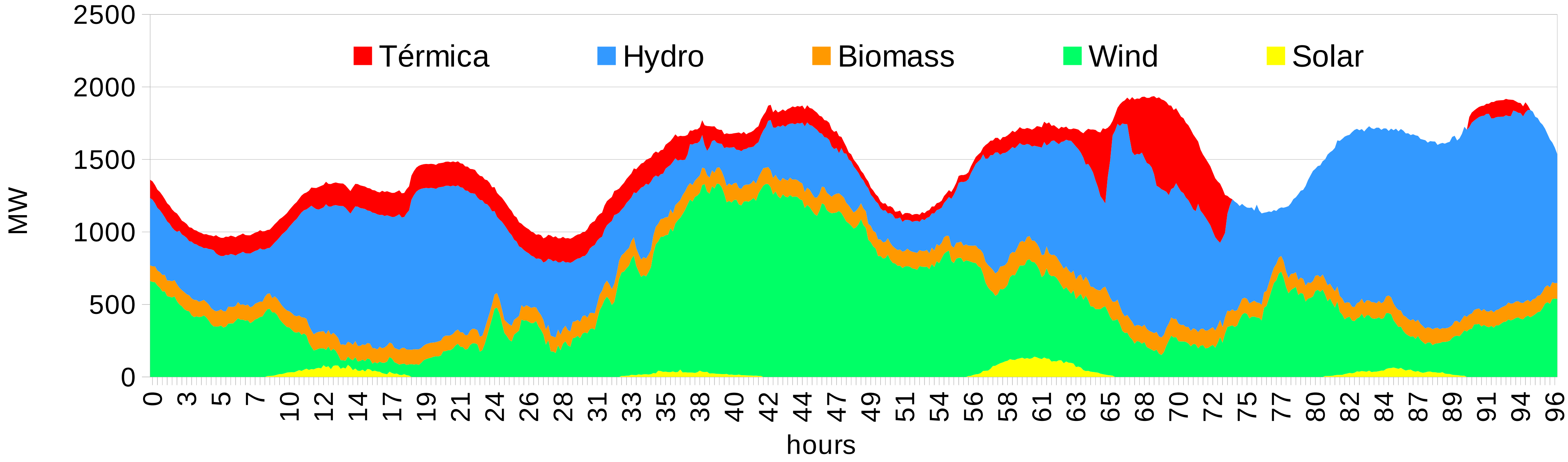
$$u = P(X, r, t)$$

$$Dim(u) \times N_{X_1} \times N_{X_2} \ldots \times N_{X_{Dim(X)}} \times N_{r_1} \times N_{r_2} \ldots \times N_{r_{Dim(r)}} \times N_t$$

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

… Makes sense?

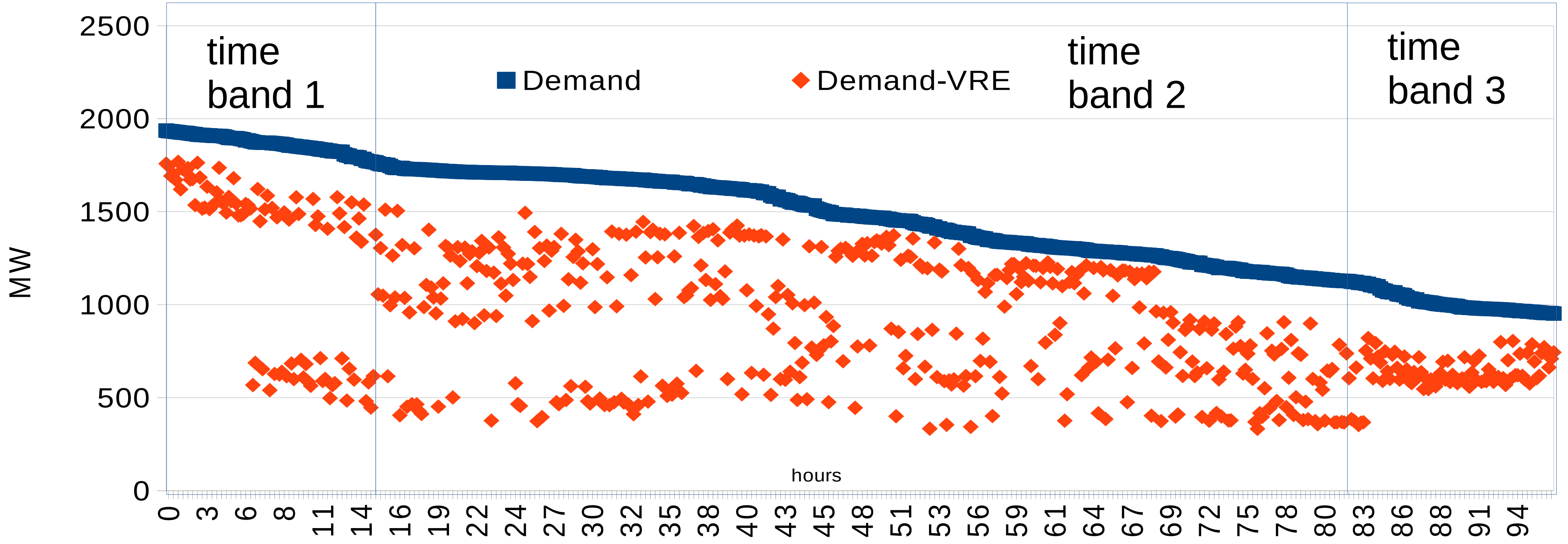
Only an example, 4 days of july-2018-Uruguay



Source: ADME - SCADA ten-minute time series

Time-Bands (Patamares)
defined by the Monotonous Load Curve
… Makes sense?

better use Net-Demand instead of Demand



Source: ADME - SCADA ten-minute time series

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

El Niño, Hydro, Wind, Solar, Demand, Temperature. (correlated processes)

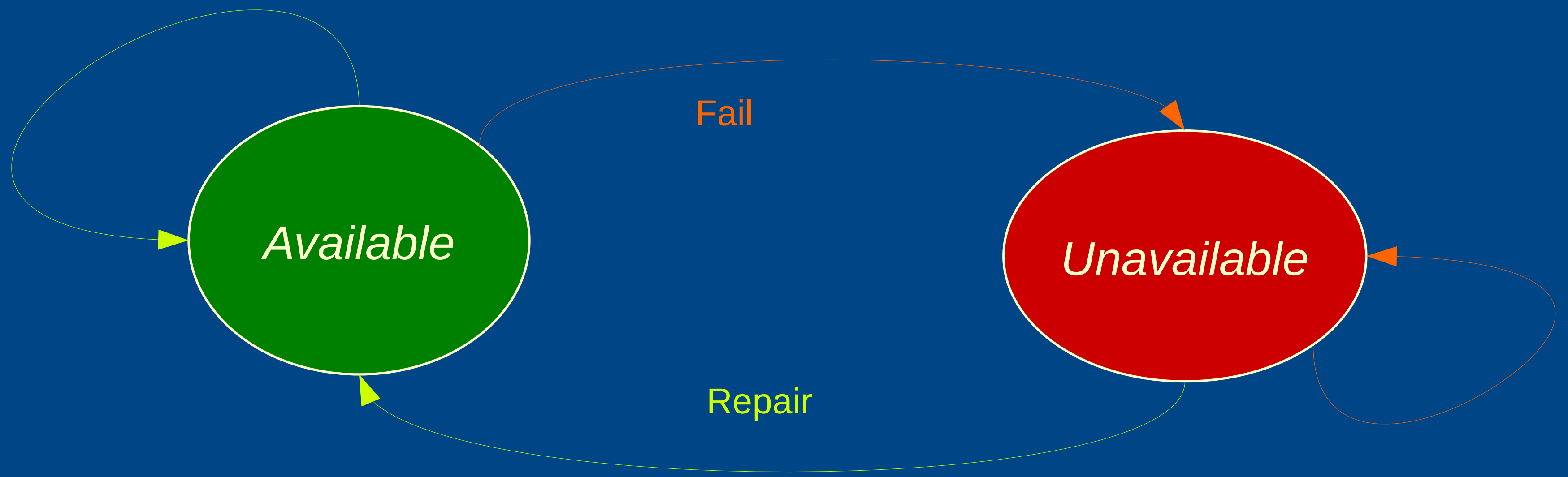
Equipment availability (independent booleans)

We are managing faster dynamics, therefore, the correlation between the different resources has greater importance.

We need models of variability that correctly represent the correlation between resources and the correlation with the past.

That is, we have to represent the inertia behind the stochastic variables.

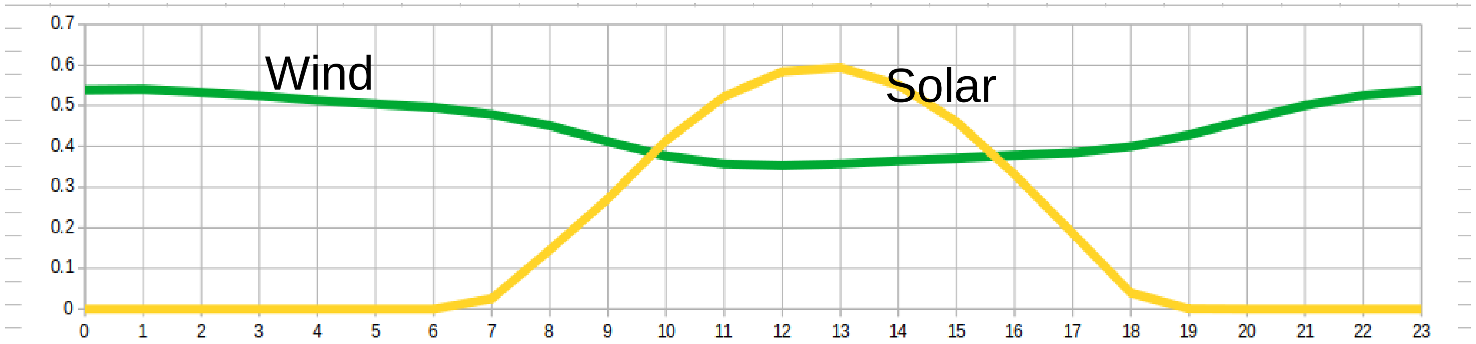
Availability of generators, power transmission lines, etc.

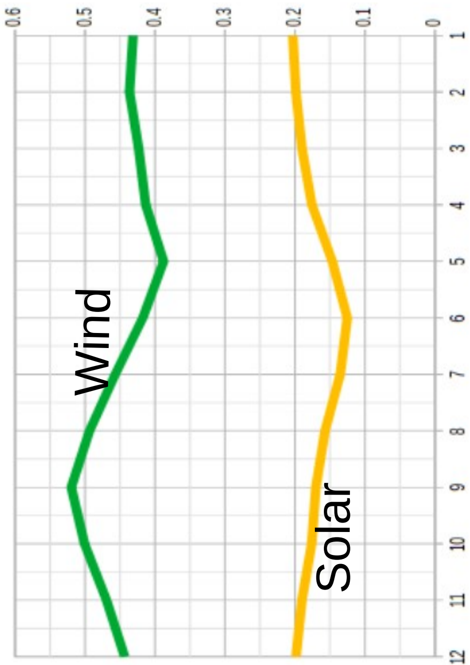


If we do not represent the state of the availability when simulating with small time-steps, the consequences of the inertia of the fault-repair process are underestimated.

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

Wind, Solar and Demand correlations.





Demand

	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23
1	1253	1138	1046	1002	987	993	1008	1017	1094	1171	1225	1275	1309	1339	1348	1349	1338	1316	1266	1219	1241	1413	1424	1365
2	1192	1090	1015	973	958	969	1011	1020	1073	1140	1187	1230	1256	1278	1278	1274	1265	1248	1211	1175	1250	1391	1354	1283
3	1097	987	905	856	837	841	878	926	962	1026	1082	1117	1142	1143	1136	1125	1116	1112	1107	1129	1302	1343	1286	1207
4	1125	1008	911	853	830	832	862	945	994	1052	1106	1134	1162	1161	1150	1132	1122	1120	1132	1263	1373	1366	1313	1236
5	1228	1096	981	912	883	883	914	1009	1101	1153	1217	1246	1267	1253	1236	1216	1201	1204	1265	1444	1484	1489	1438	1354
6	1324	1182	1051	972	939	938	969	1067	1186	1248	1325	1359	1374	1353	1332	1309	1289	1285	1363	1554	1584	1591	1546	1456
7	1384	1239	1103	1014	973	966	991	1082	1193	1272	1364	1411	1435	1427	1413	1390	1366	1357	1399	1577	1625	1637	1594	1508
8	1358	1211	1079	1002	969	966	999	1099	1191	1287	1361	1382	1399	1375	1351	1321	1292	1277	1297	1465	1586	1606	1568	1480
9	1263	1136	1022	953	923	922	953	1011	1089	1178	1241	1269	1294	1289	1278	1256	1235	1227	1235	1332	1486	1504	1468	1388
10	1069	962	893	860	857	880	948	1004	1071	1126	1158	1189	1188	1176	1154	1136	1124	1122	1115	1145	1337	1368	1291	1183
11	1082	975	907	875	874	900	935	1005	1078	1140	1177	1213	1219	1209	1192	1186	1181	1178	1159	1153	1259	1363	1303	1207
12	1323	1221	1139	1090	1071	1074	1061	1103	1185	1262	1311	1366	1401	1425	1445	1451	1436	1401	1343	1288	1295	1443	1454	1411

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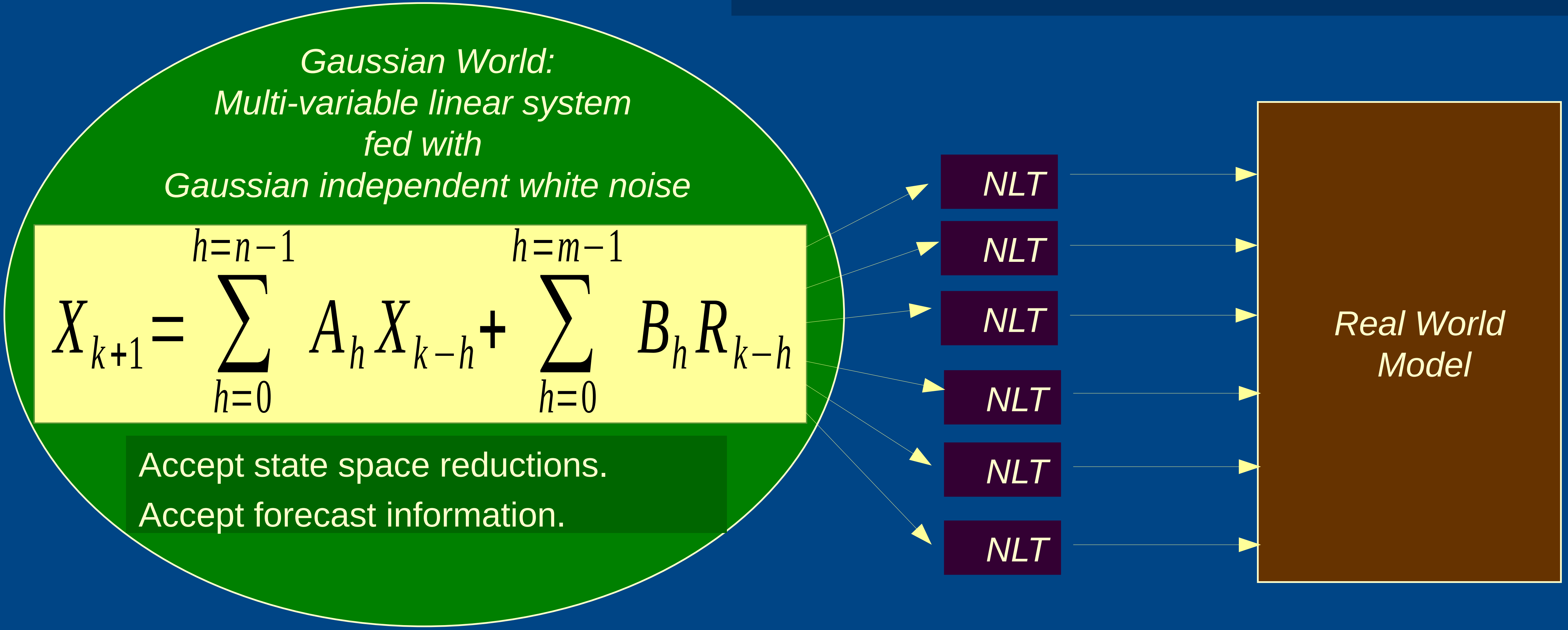
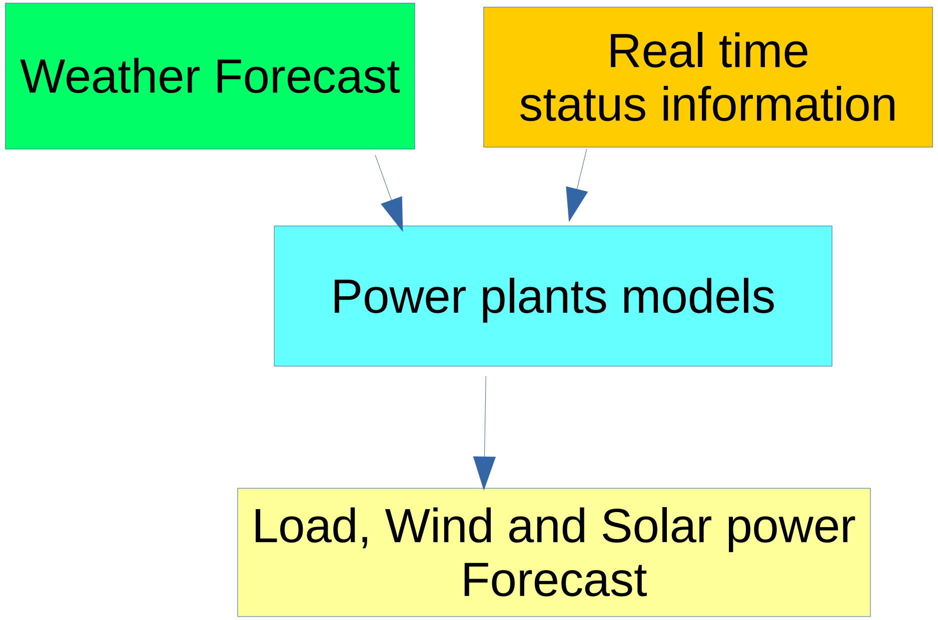
CEGH modeling.

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



PRONOS 2016-2017

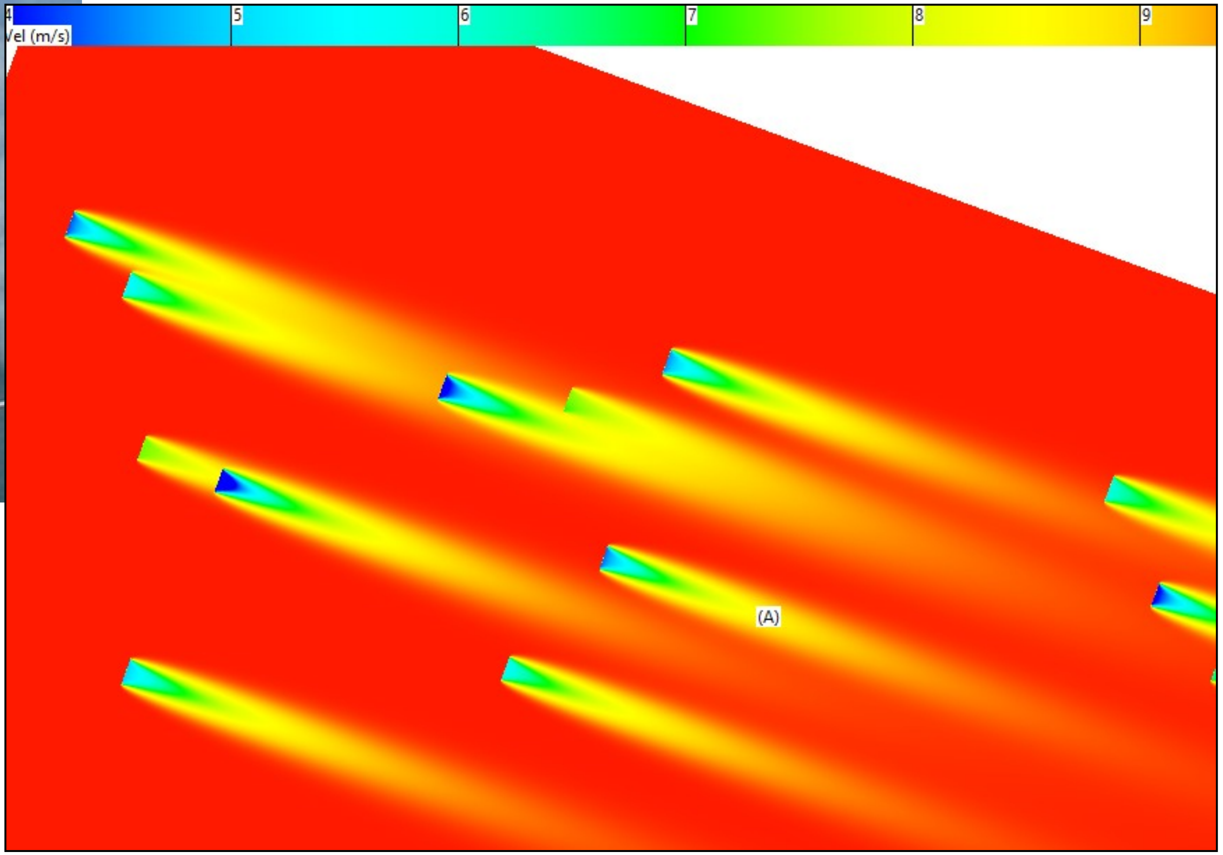


Fundación Julio Ricaldoni
INGENIERIA EN EL URUGUAY

BANCO DE DESARROLLO DE AMÉRICA LATINA

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

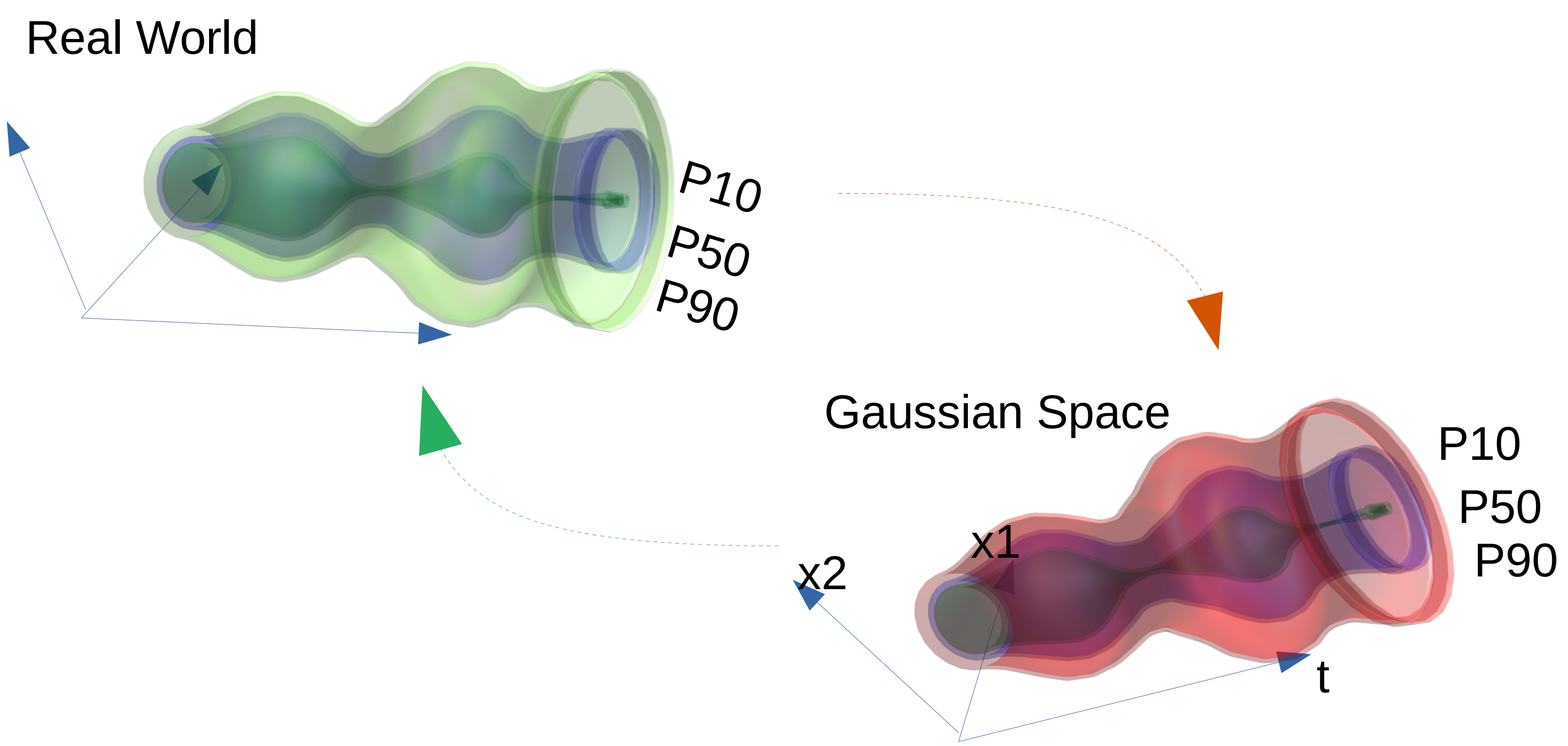
ADME_Data y ADME_WindSim



Operator without forecasts

Operator with forecasts

Treatment of forecasts in CEGH modeling.
Gaussianization



Ease integration of FORECASTS in CEGH modeling.

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

biases:

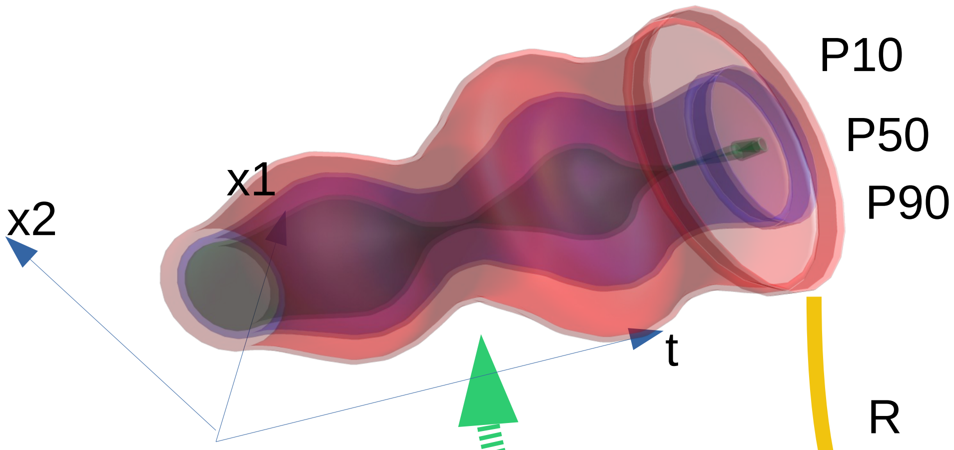
$$S_k = \begin{bmatrix} s_{1,k} \\ \dots \\ s_{n,k} \end{bmatrix}$$

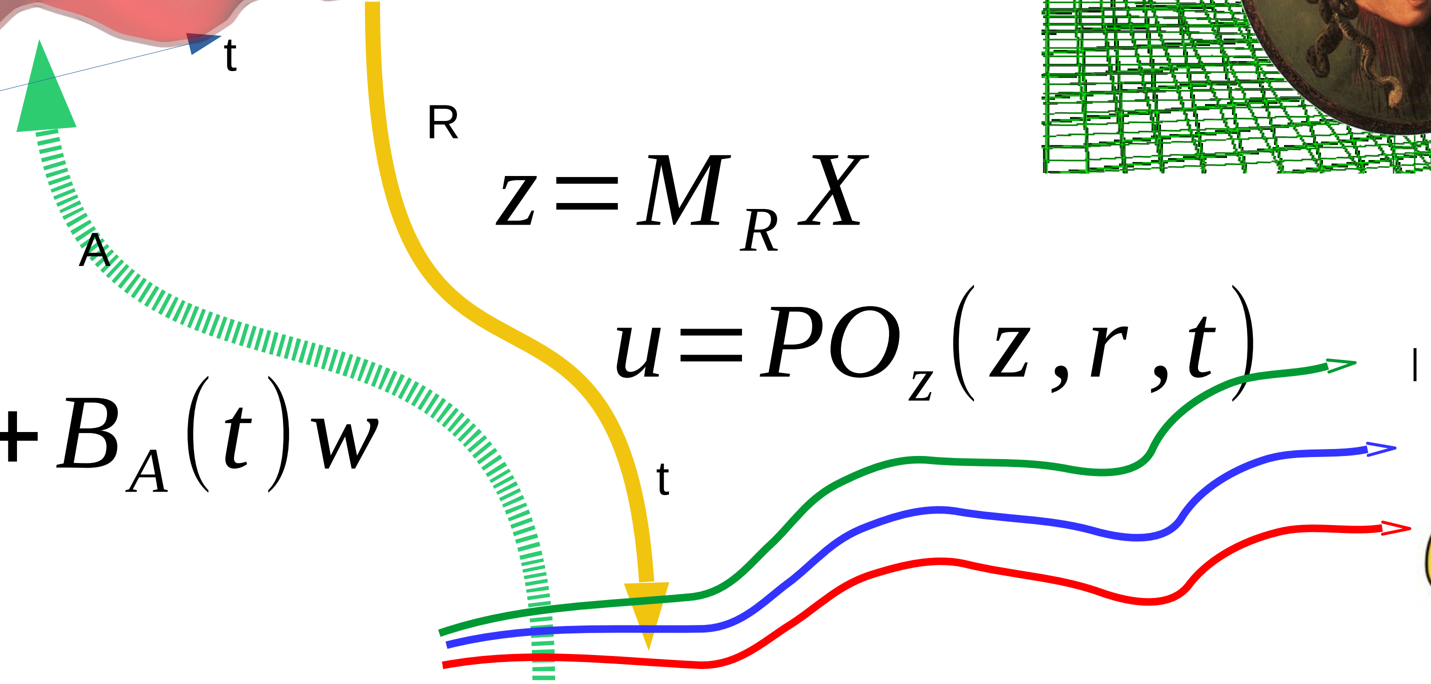
attenuators:

$$F_k = \begin{bmatrix} f_{1,k} & 0 & \dots & 0 \\ 0 & f_{2,k} & \dots & 0 \\ 0 & \dots & 0 & f_{n,k} \end{bmatrix}$$

The biases (S) change the 50% probability guide and the attenuation factors (F) regulate the noise injection, allowing to go from a Deterministic Forecast (F = 0 = null noise) to the disappearance of the forecast (S = 0; F = 1 =historical noise).

Treatment of forecasts in Gaussian space with reduction in CEGH modeling.



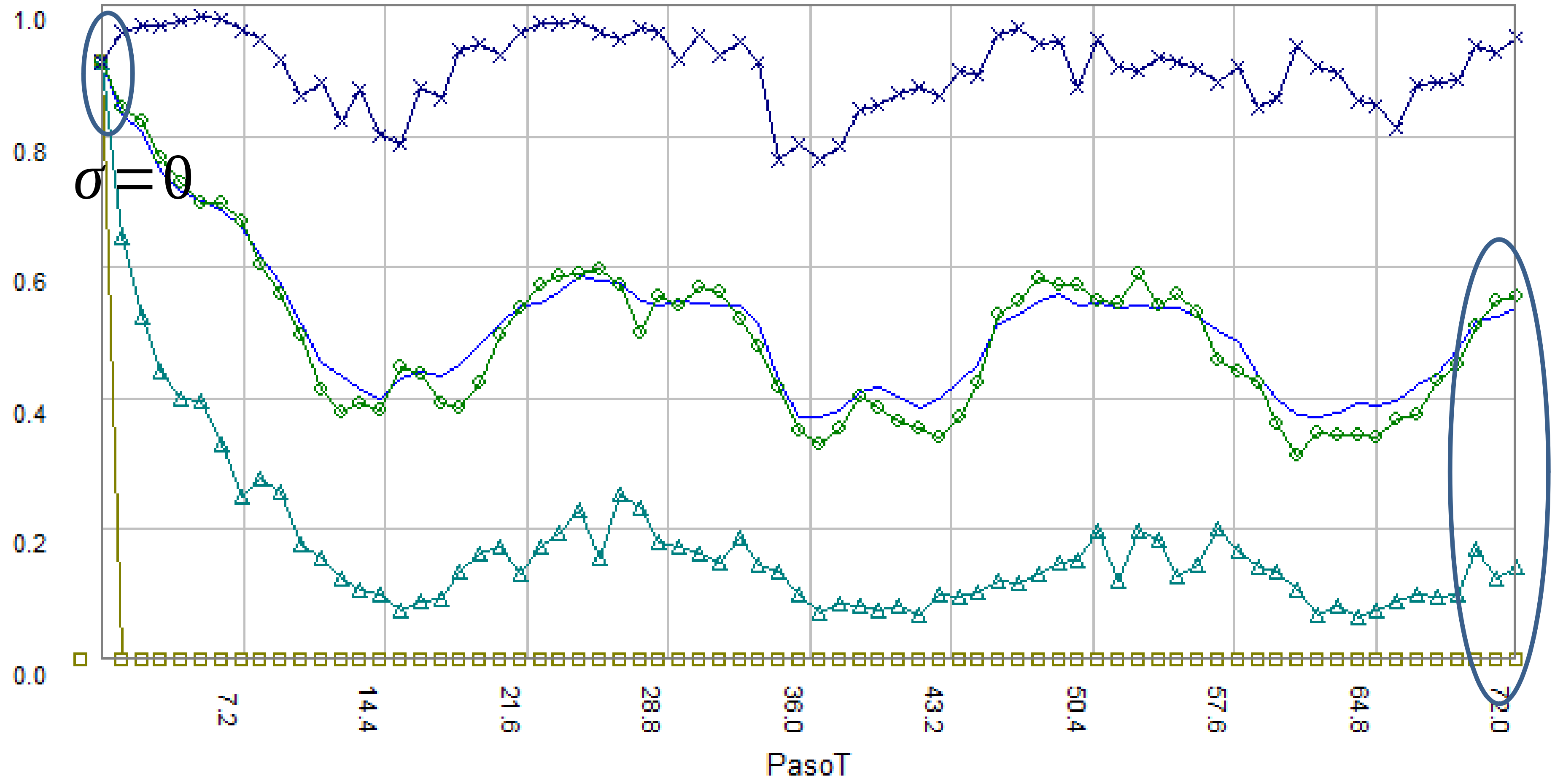


$$z=M_R X$$

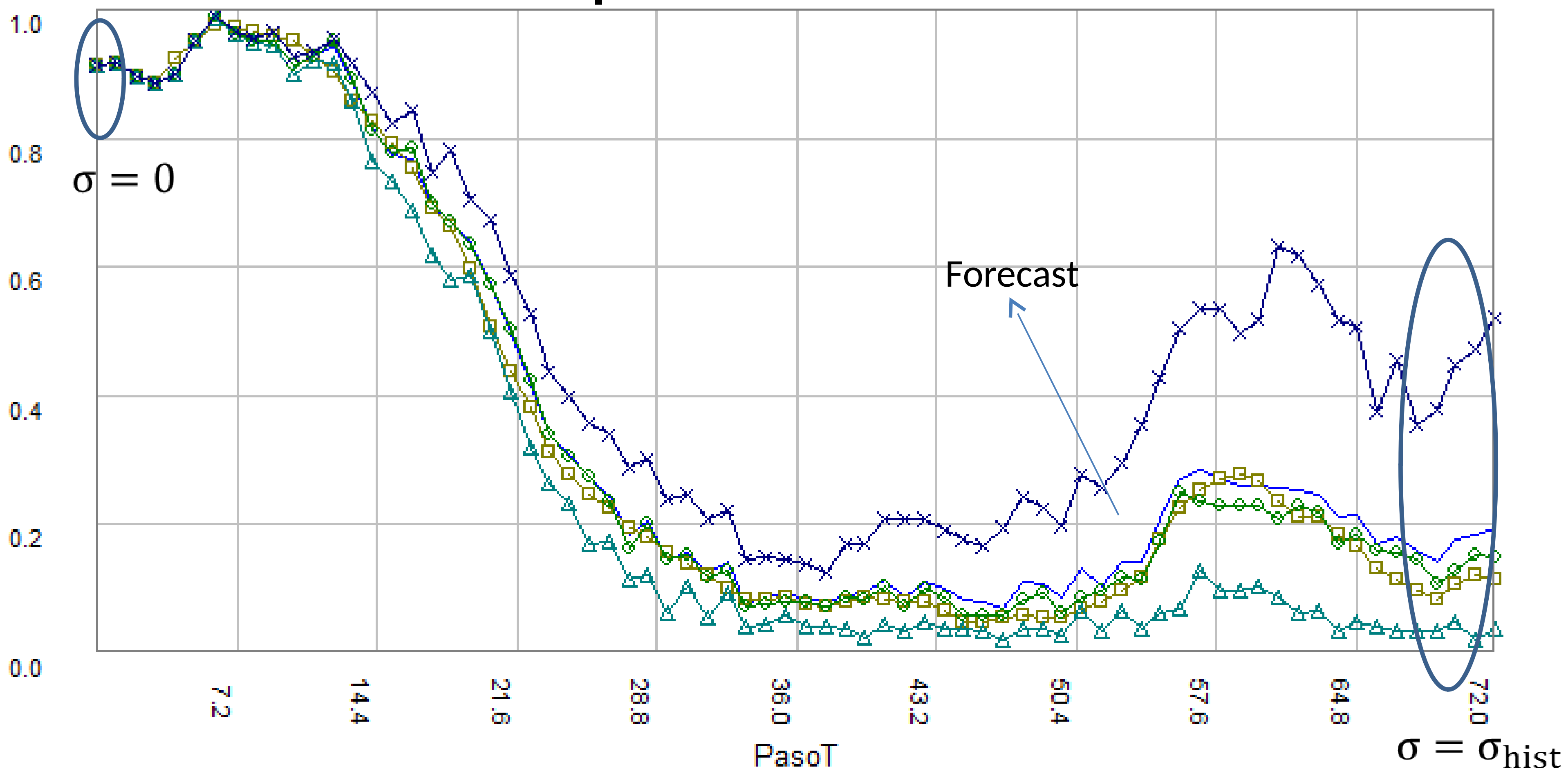
$$u=PO_z(z,r,t)$$

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

Programming the enegy dispatch without windpower forecasts.



Programming the enegy dispatch with 72h of windpower forecasts.

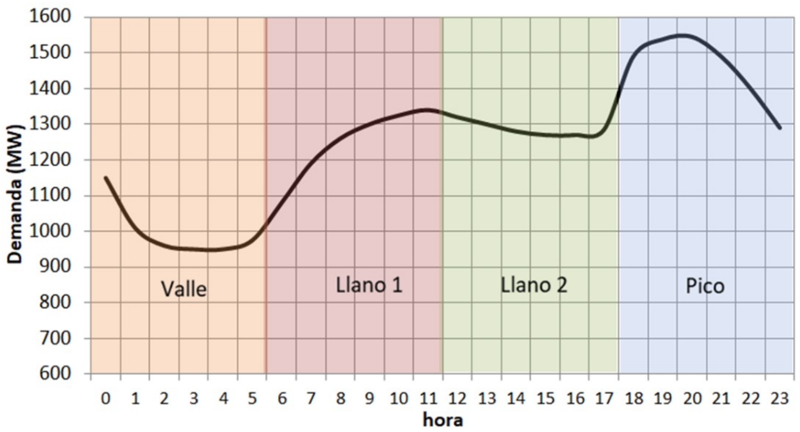


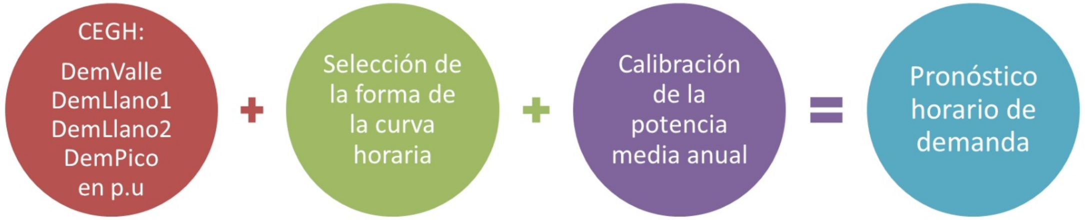
Demand Stochastic Model

Eng. Eliana Cornalino

La demanda diaria se descompone en:

- 4 tramos de energía (valle, llano1, llano2 y pico)
- 3 tramos de curva horaria (valle, llano 1y2 y pico)





Modelo CEGH de paso diario, ciclo anual y filtro variable

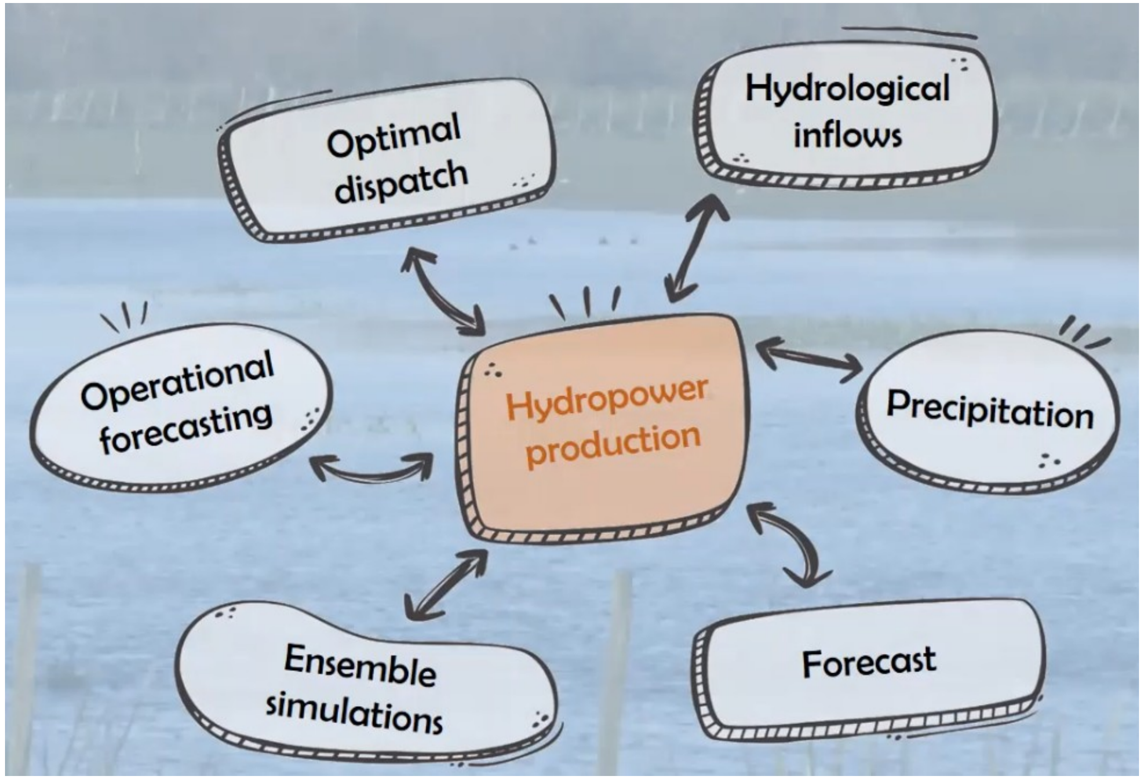
Matrices A y B → X[k+1]=AX[k]+BX[k]

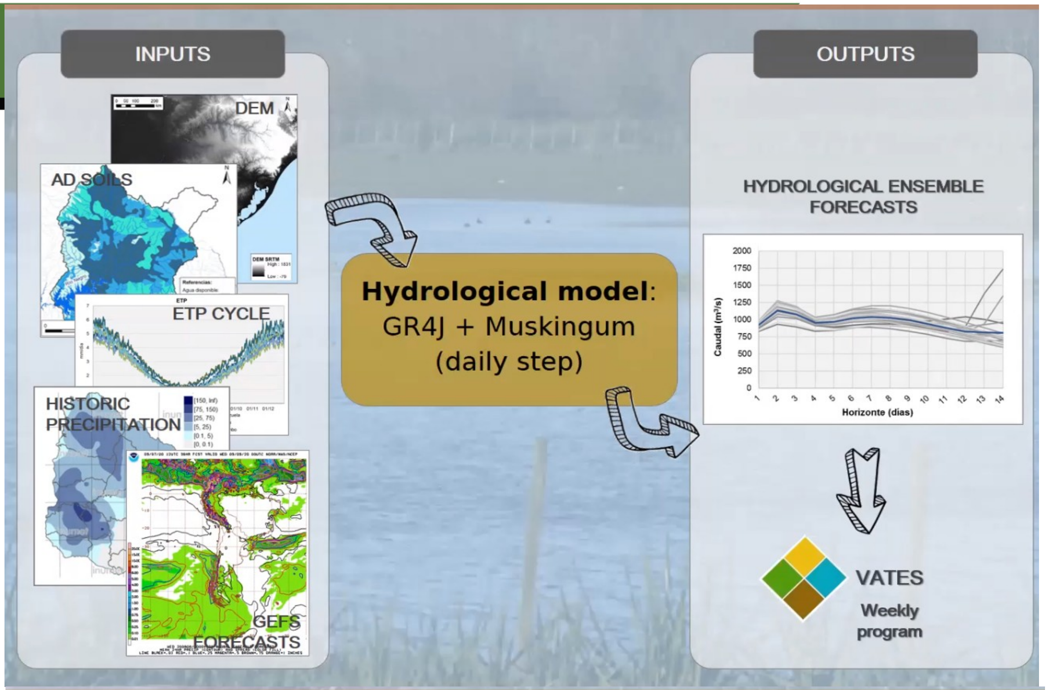
365 matrices A y B
Una para cada paso del ciclo

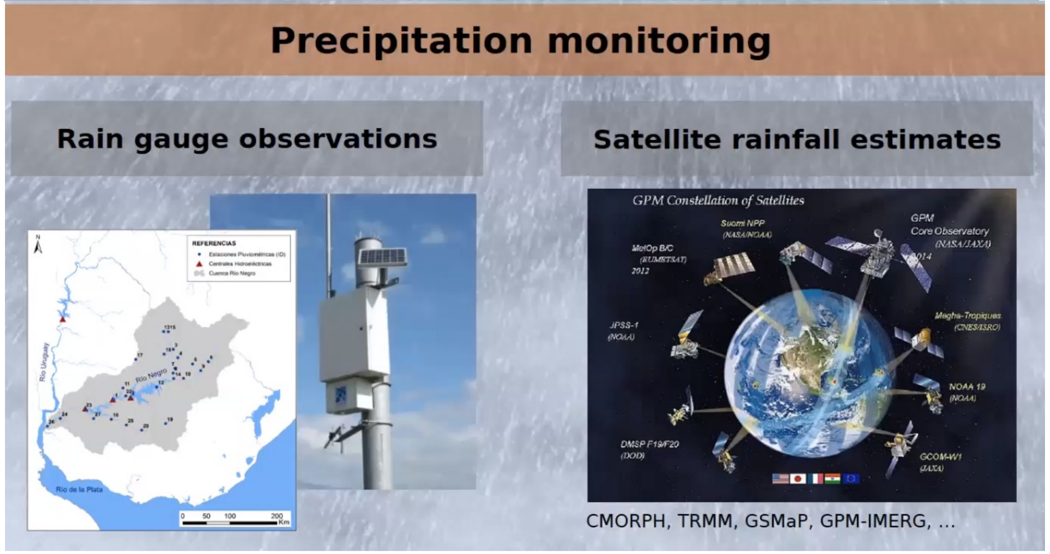
For more information see: https://youtu.be/SvidemGQdG4

Hydrological modeling

Eng. Alejandra de Vera





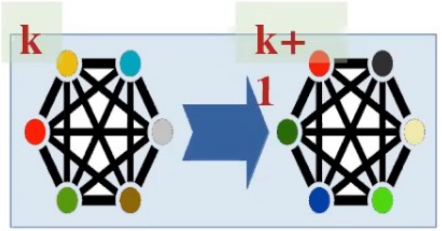


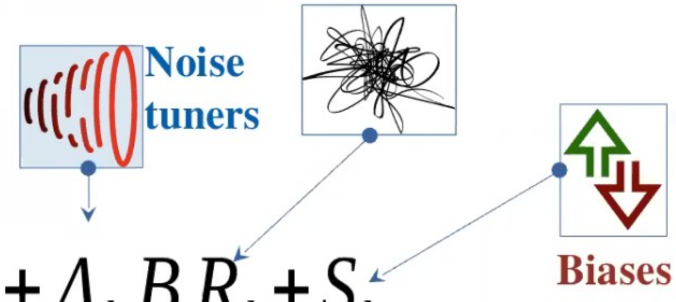
For more information see: https://youtu.be/DYvZLeotxEk

Assimilation of Forecast Ensembles in CEGH Models.

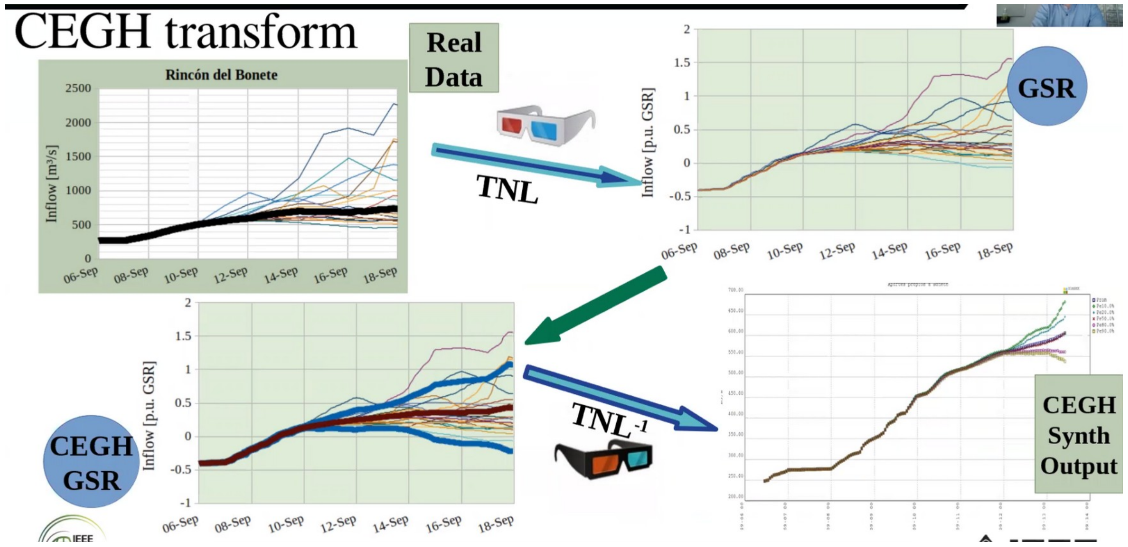
Eng. Guillermo Flieller

CEGH forecast coupling





$$X_{k+1} = \sum A\, X_k + \Lambda_k\, B\, R_k + S_k$$

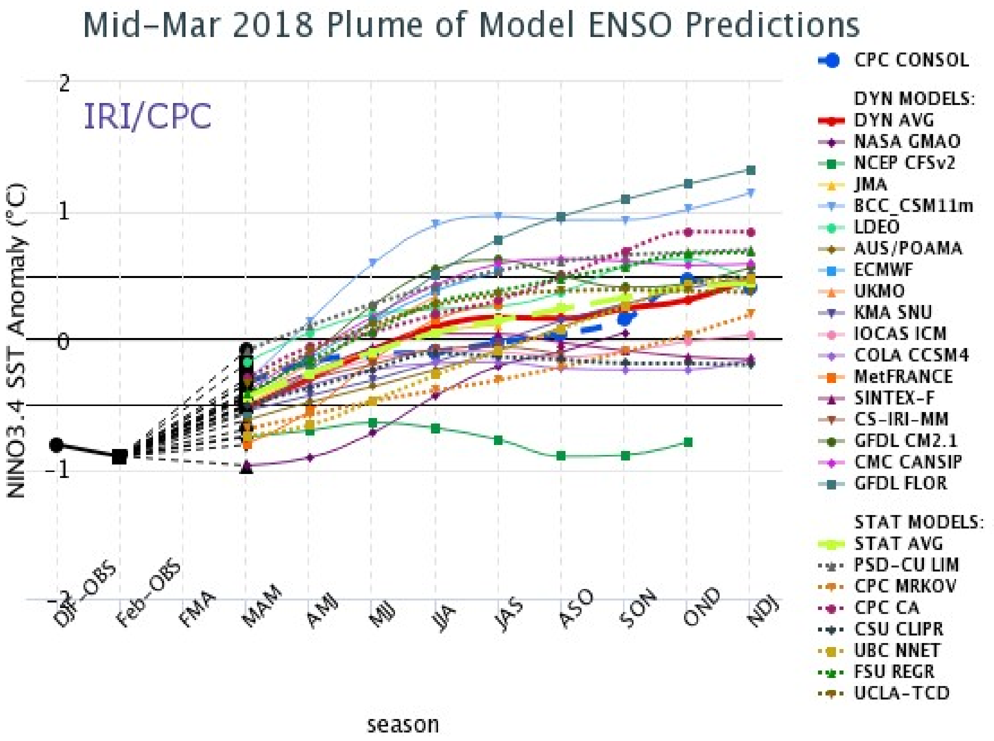


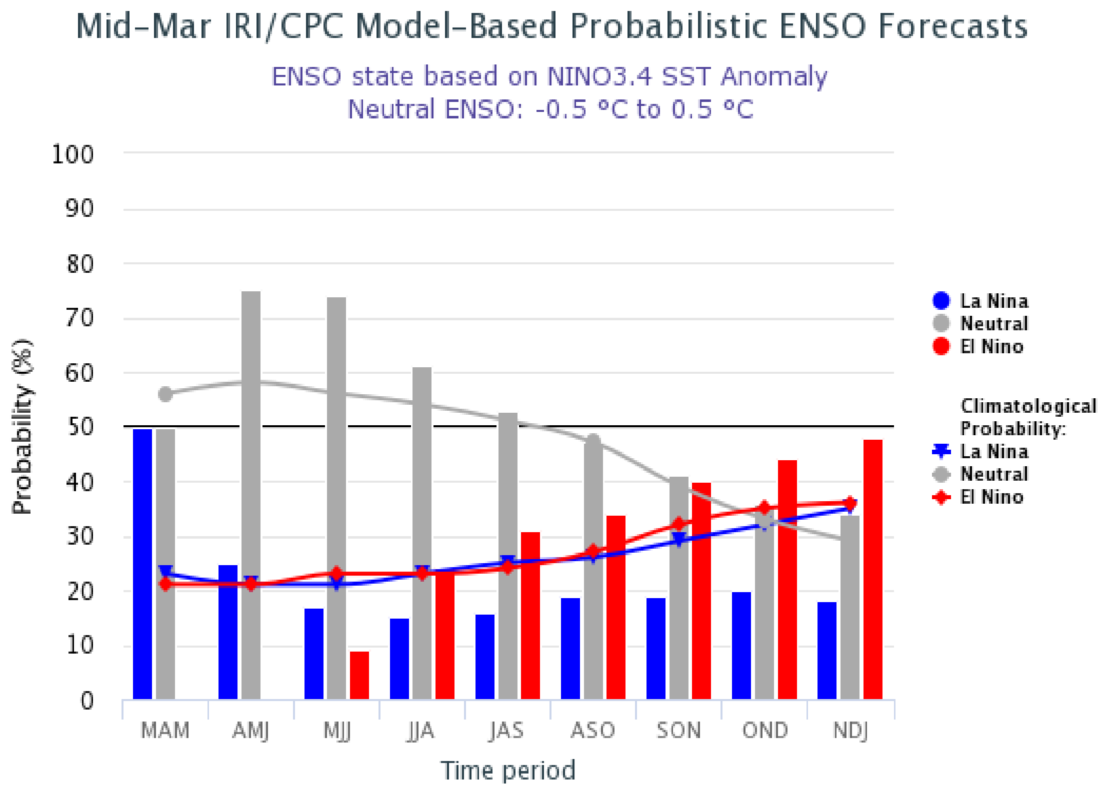
Application

- Hydraulic CEGH into VATES
  - 21-member 14-day ensemble forecasts of water inflow
  - ENSO and export prices
- Optimized and simulated hourly
- Week-ahead load dispatch programming

For more information see: https://youtu.be/glheJY9PPc4

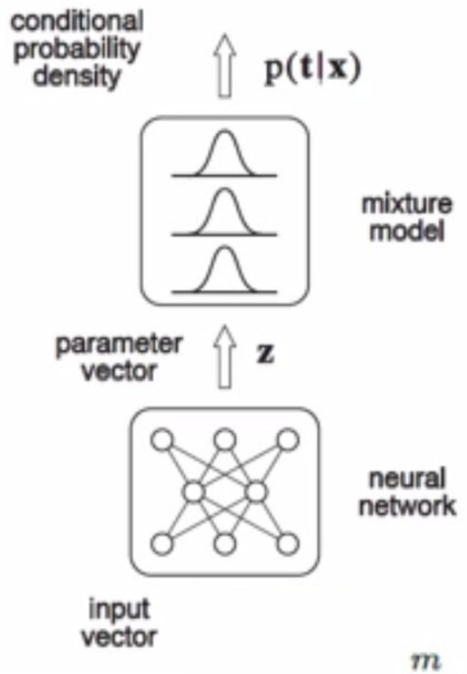
Considering the ENSO Forecasts

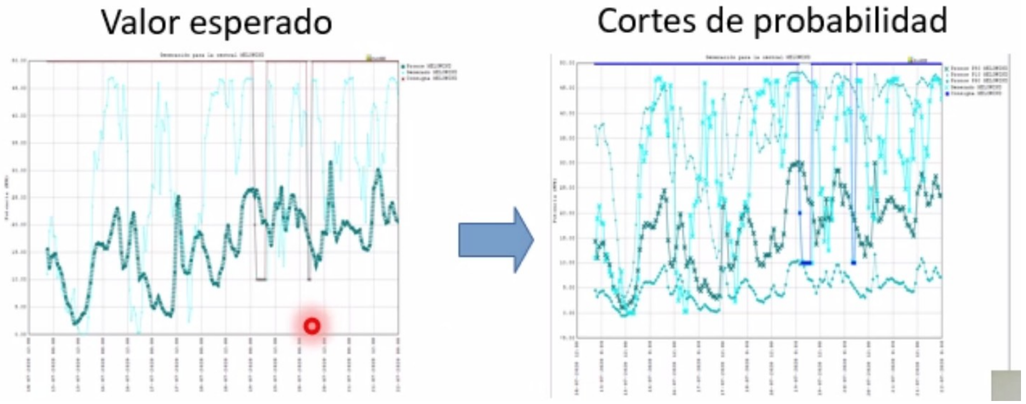




Modeling Wind and Solar Power Forecasts using Mixture Density Networks

Eng. Damián Vallejo.





$$p(t|x) = \sum_{i=1}^{m} \alpha_i(x)\phi_i(t|x)$$

$$\phi_i(t|x) = \frac{1}{\sqrt{2\pi}\sigma_i(x)} \exp\left\{-\frac{1}{2}\left(\frac{t-\mu_i(x)}{\sigma_i(x)}\right)^2\right\}$$

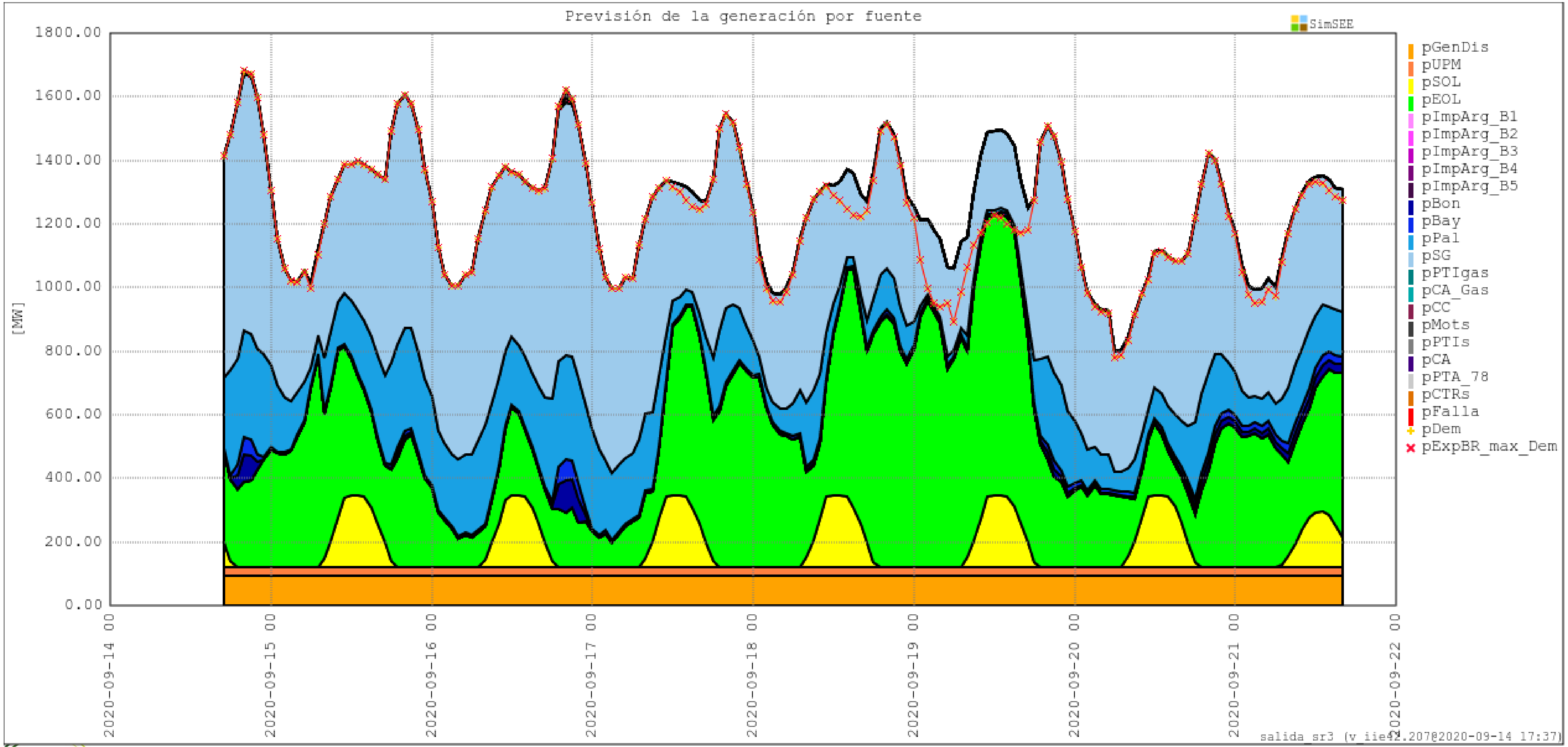
For more information see: https://youtu.be/ZDUhUMfI-7o

VATES

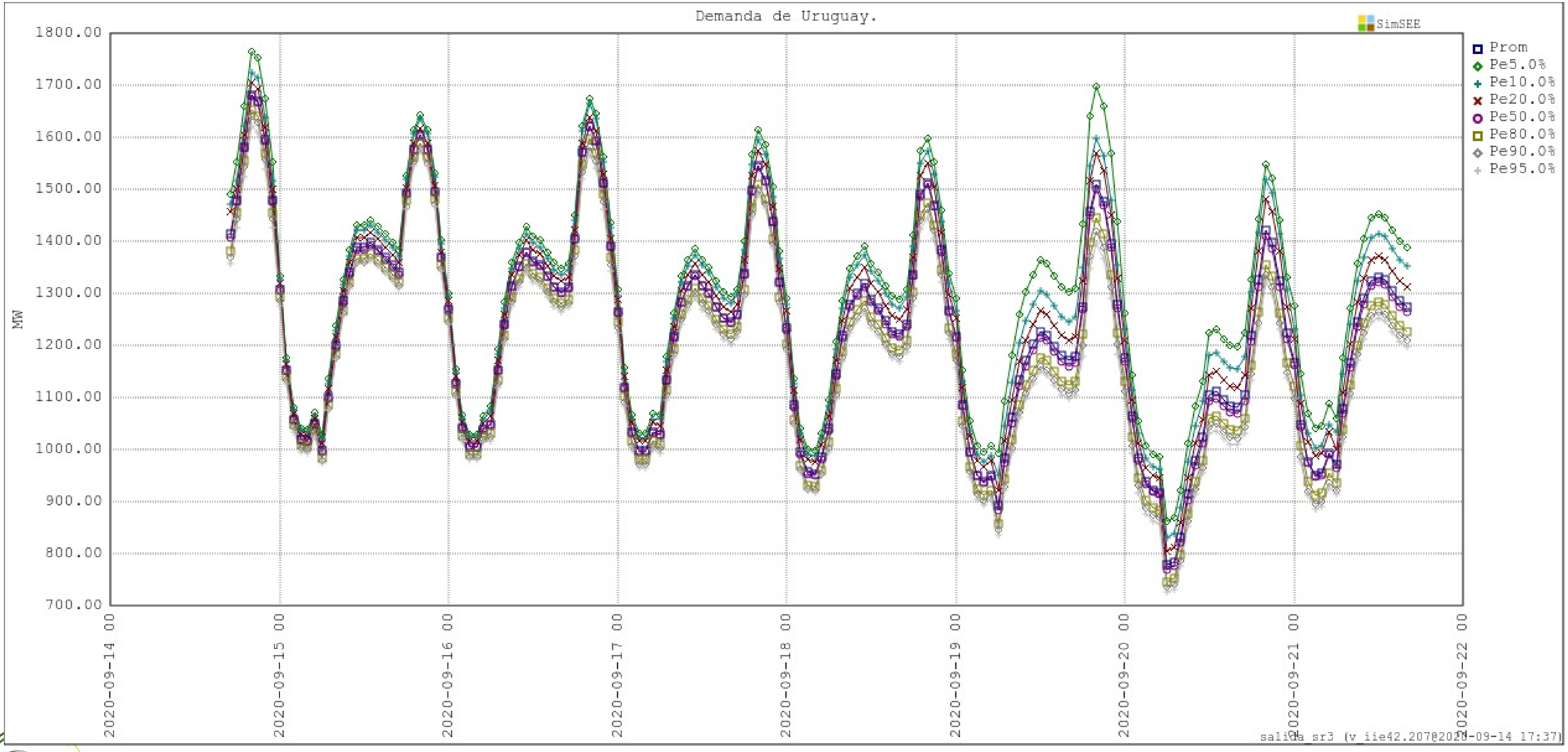
Continuous forecast of the next 168 hours of optimal operation.

https://vates.adme.com.uy

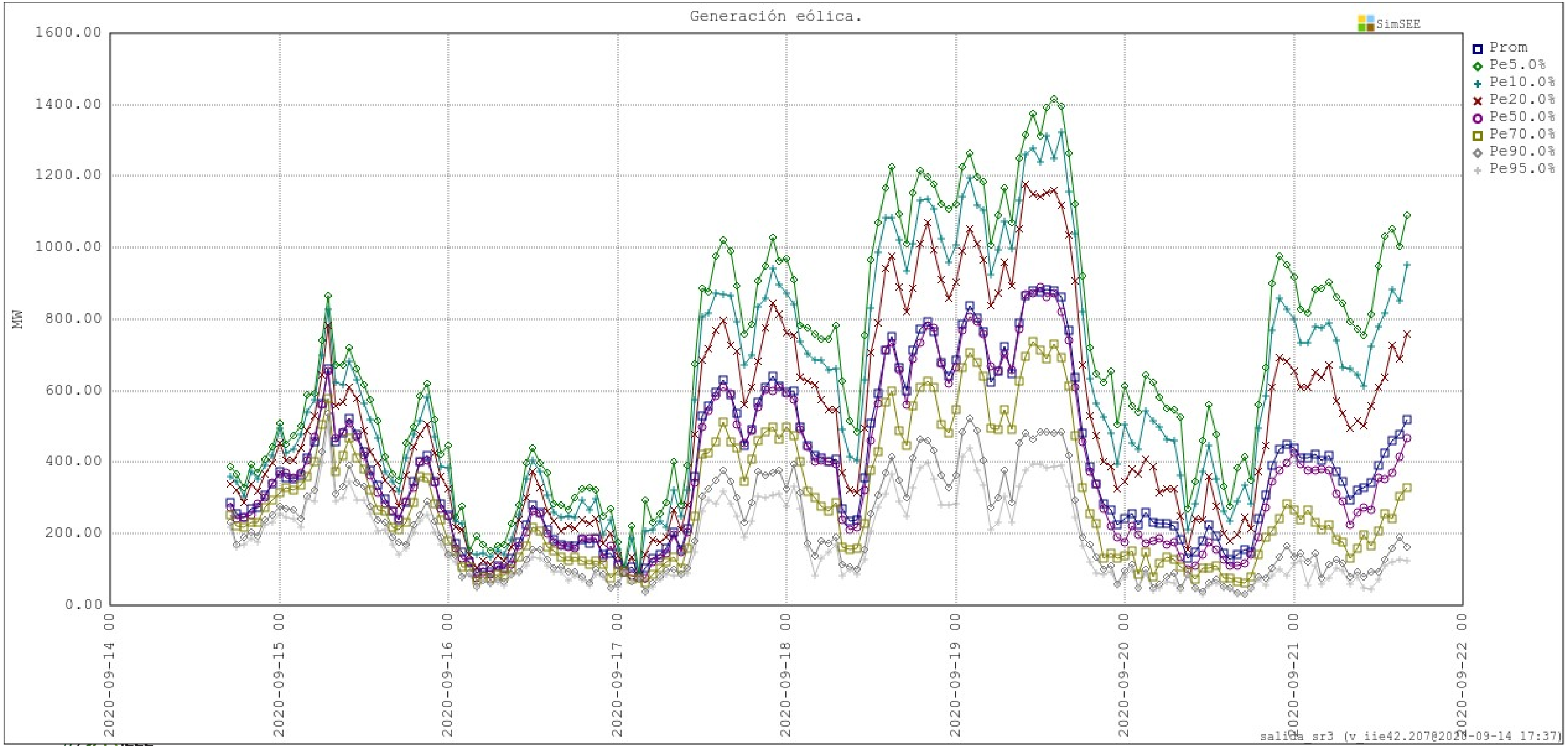
Expected generation by source. (Example from ADME's WEB)



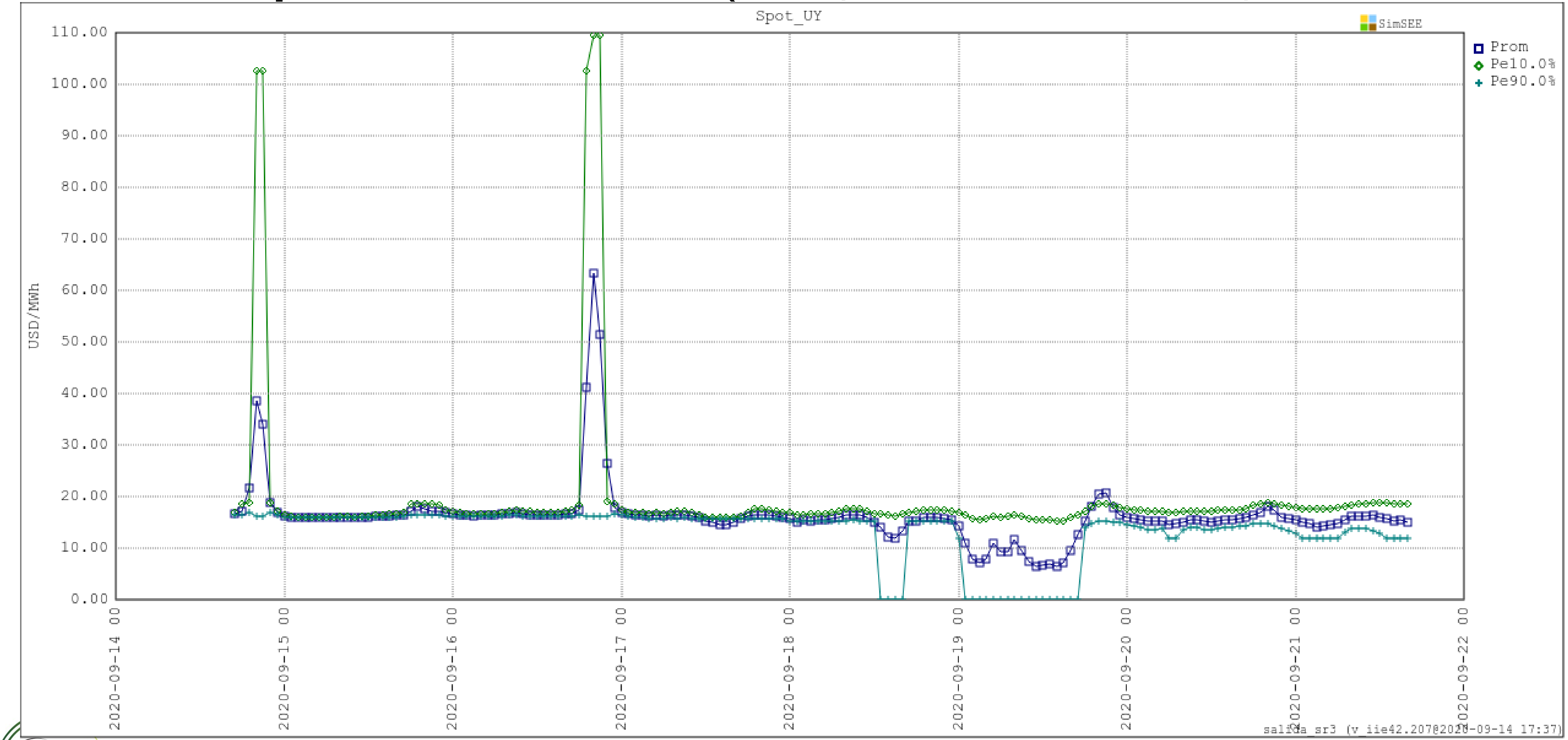
Next 168 h, System Load forecast. (Example from ADME's WEB)



Next 168 h, Windpower forecast. (Example from ADME's WEB)



Next 168 h, Spot Price forecast. (Example from ADME's WEB)



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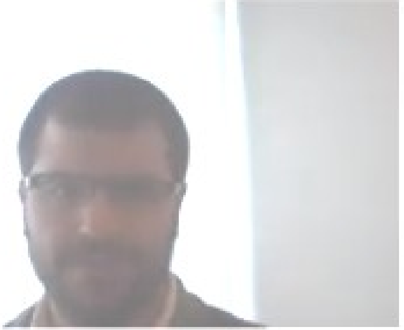
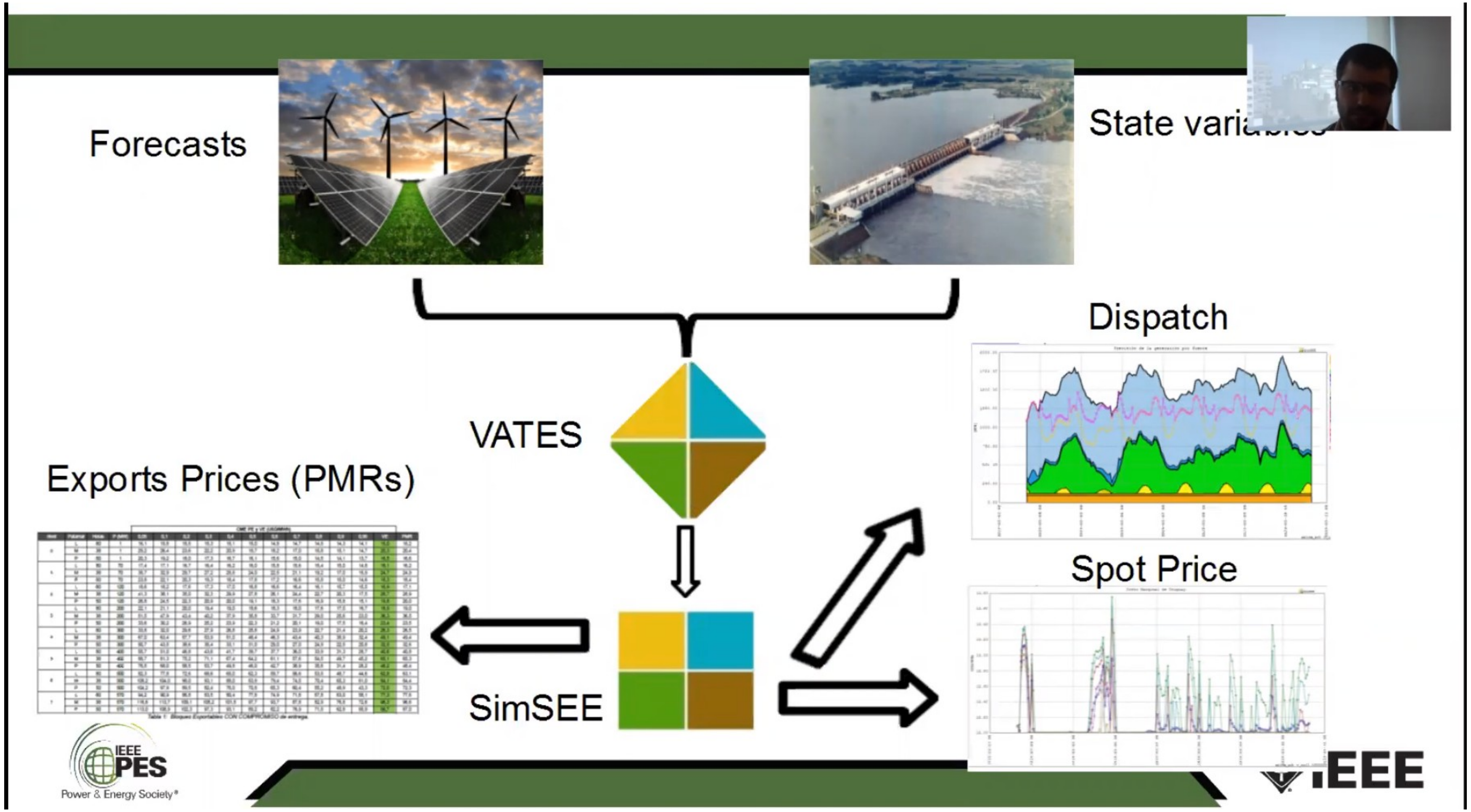
Determination of Exportable Energy Blocks

Eng. Felipe Palacio





For more information see: https://youtu.be/F7h43i3sxU0

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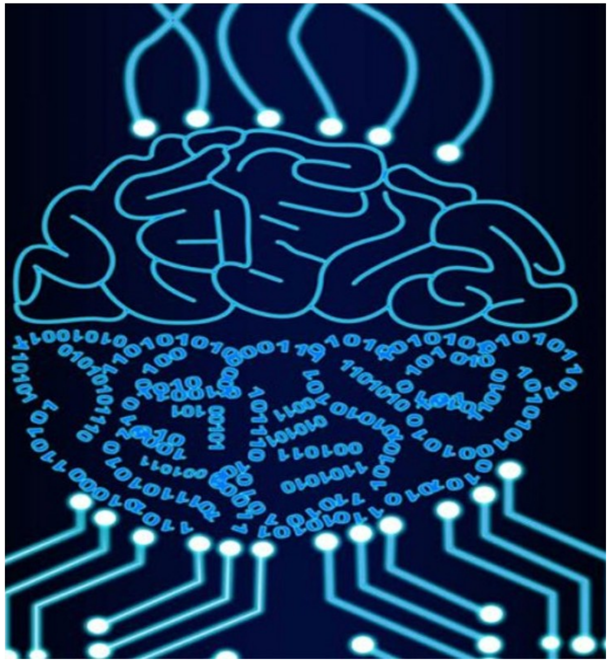
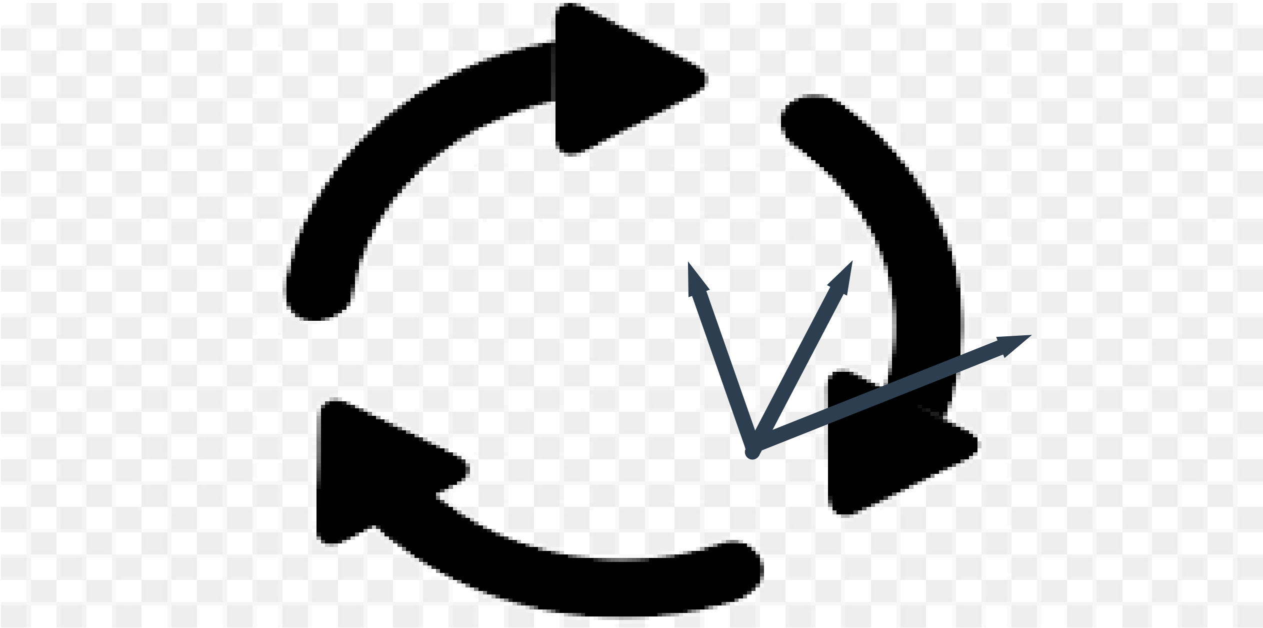
What we are working on now for the future.





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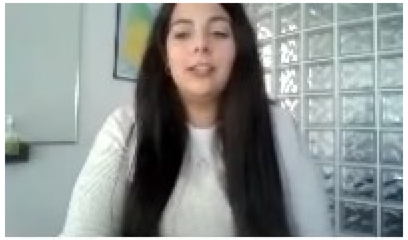
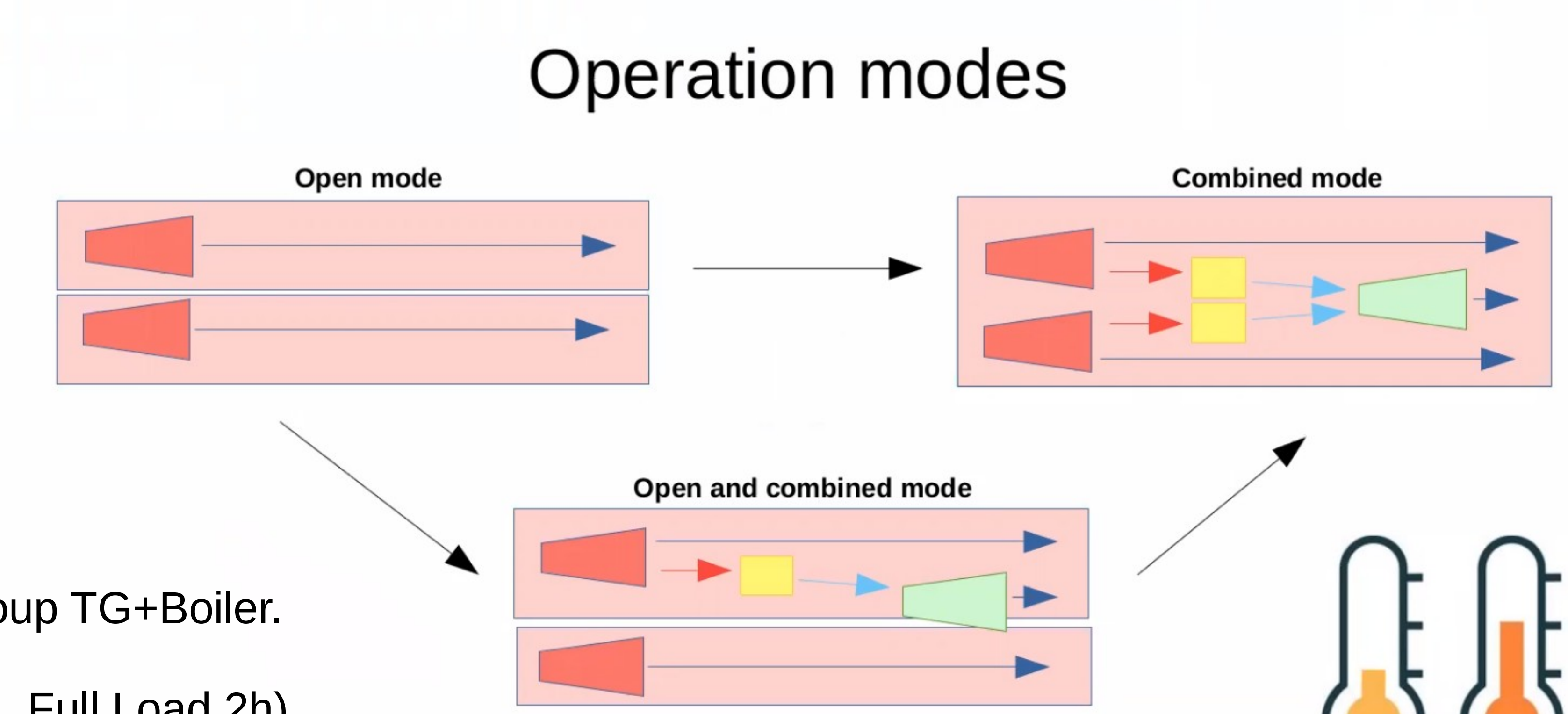
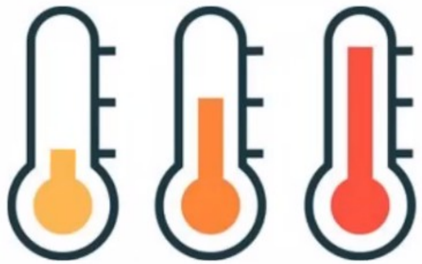
Combined Cycle Model.

Eng. Vanina Camacho







2 State variables for each group TG+Boiler.

- Timer_TGtoCC_ (Purge 4h, Full Load 2h)
- Boiler_temperature (startup type:, warm, hot, cold)

For more information see: https://youtu.be/_EcEf4w8yn4

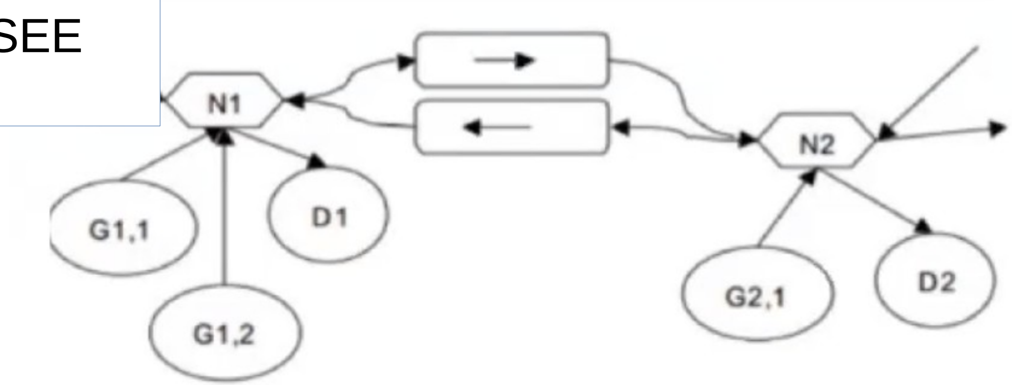
Optimal dispatch with network representation in SimSEE.

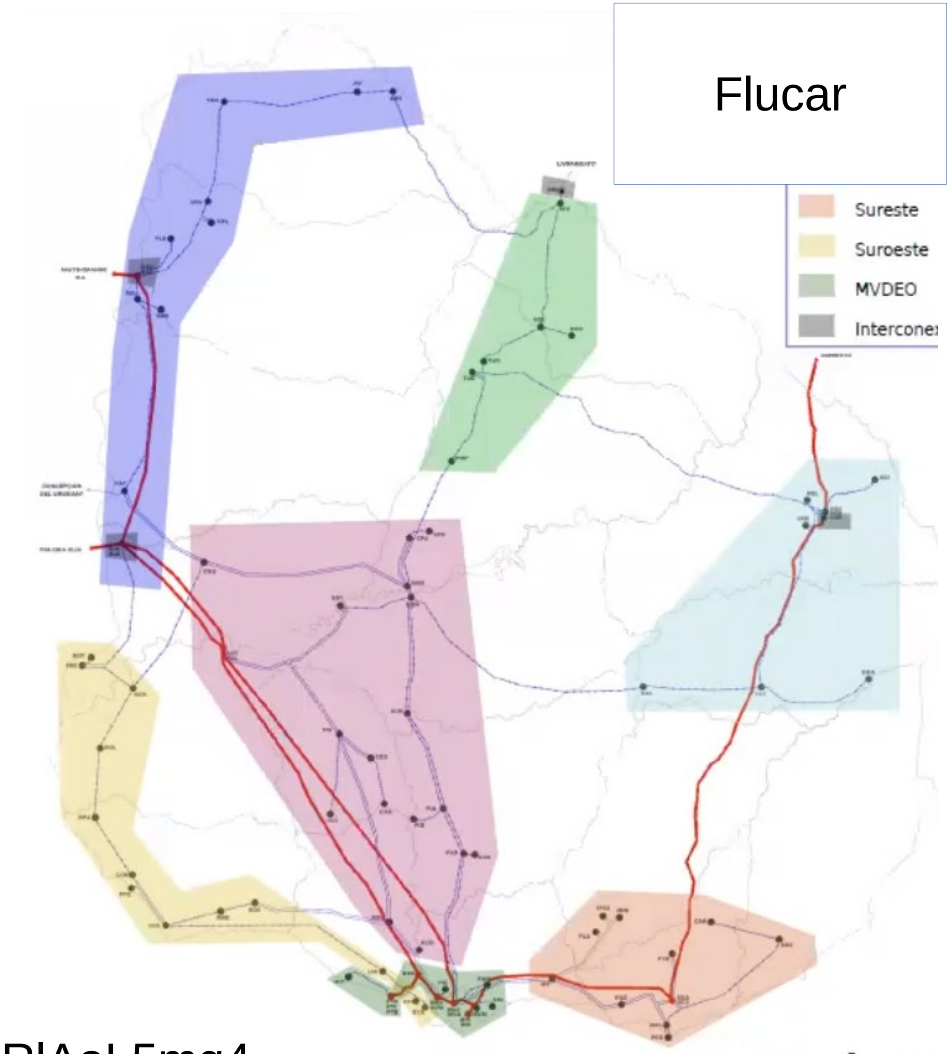
Eng. Ignacio Reyes

Flucar

iteration

SimSEE





For more information see: https://youtu.be/jHRIAaL5mq4

Bellman's curse of dimensionality.

Operation Policy:

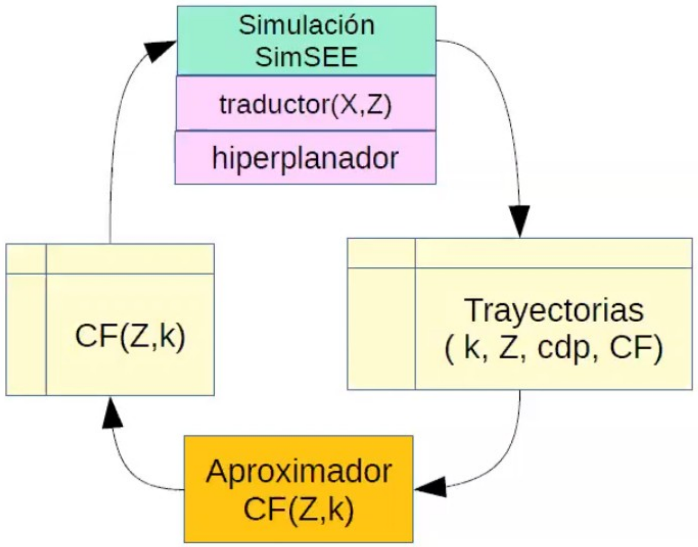
$$u = P(X, r, t)$$

SimSEE Self-Learning a pesudo-optimal Operation Policy to Combat Bellman's Curse of Dimensionality

ANII_FSE_1_2017_1_144926 (2018-2020)
IIE-FING-UdelaR

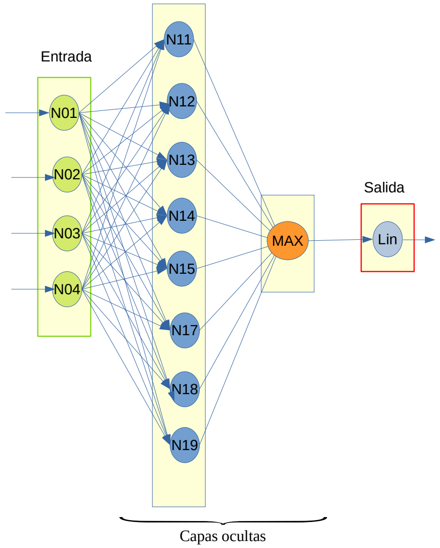
Ruben Chaer, Ignacio Ramirez, Ximena Caporale, Pablo Soubes, Damián Vallejo, Felipe Palacio, Sergio Tagliafico.

Operation policy improvement loop



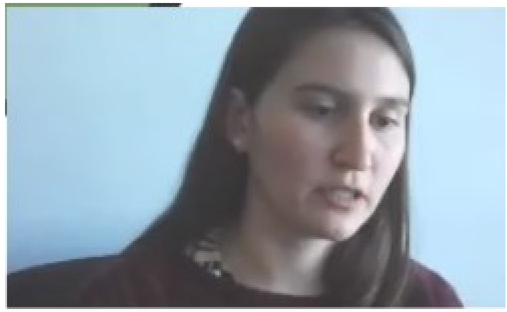
$$\min_{u,\, X_{k+1},\, CF} \left\{ ce(X_k, u_k, r_k, k) + CF \right\}$$

$$@ \left| \begin{array}{l} u \in \Omega(X_k, r_k, k) \\ X_{k+1} = f(X_k, u_k, r_k, k) \\ CF \geq a_{ik}^T X_{k+1} + c_{ik} \, ; i = 1, 2 \ldots n_h \end{array} \right.$$

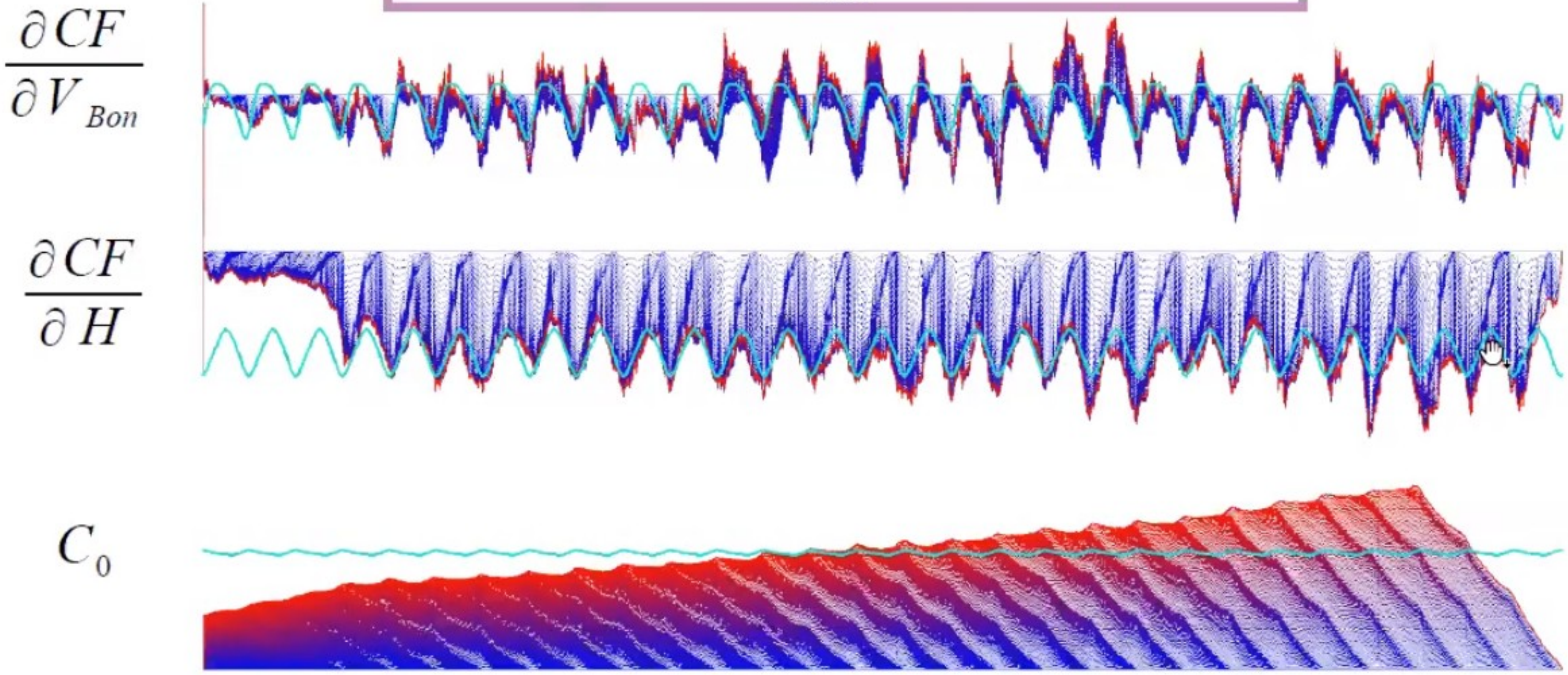


Temporal Parsimony

Eng. Ximena Caporale



$$CF(V_{Bon}, H) = \frac{\partial CF}{\partial V_{Bon}} V_{Bon} + \frac{\partial CF}{\partial H} H + C_0$$



3 x 1515 = **4542**

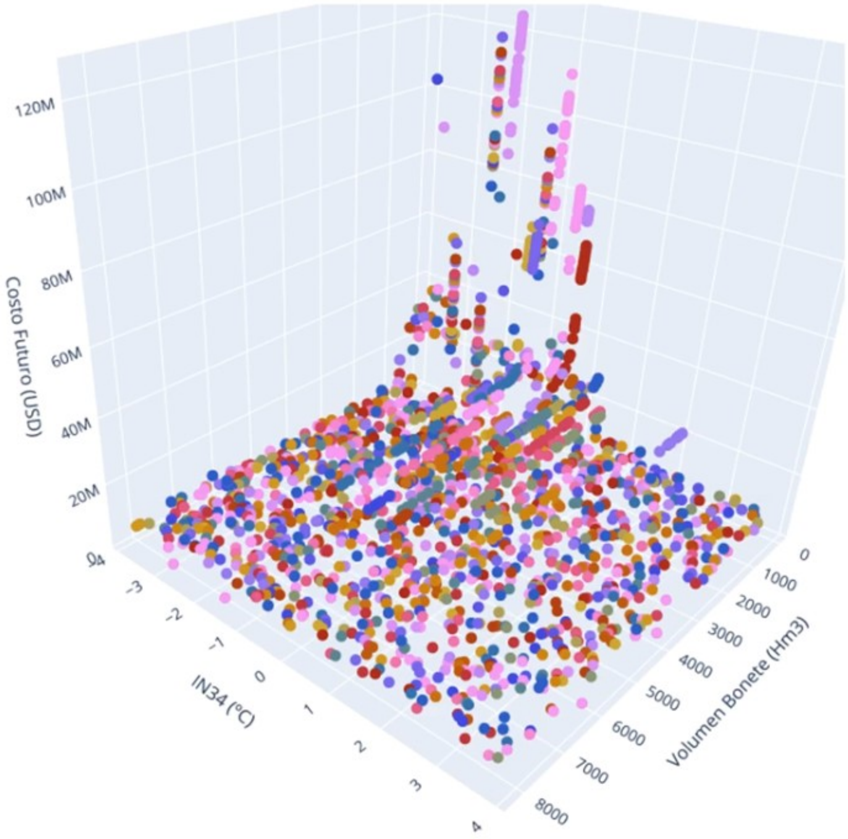
vs

3 x (1+ 2 x 3)=**21**

For more information see: https://youtu.be/4P4yriSpSBk

Exploration of state space during learning.

Eng. Pablo Soubes



For more information see: https://youtu.be/bDPUNMnwkY8

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That's all folks.
Thank you so much for your attention!

... and let's continue exploring the future!

Ruben Chaer *(IEEE-Senior Member)*
Gerente de Técnica y Despacho Nacional de Cargas - ADME.
Prof.Agr. Instituo de Ingeniería Eléctrica - FING - UdelaR.

Uruguay - September *2020*