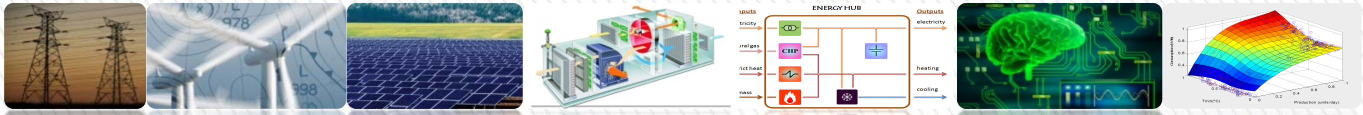


INTELLIGENT ENERGY MANAGEMENT SYSTEMS APPLIED TO INDUSTRIAL PLANTS

UNIVERSITAT POLITÈCNICA DE CATALUNYA

Departament d'Enginyeria Electrònica

MCIA

TECNIO
Be tech. Be competitive

Outline

- » **Energy service companies (ESCO)**
- » Intelligent energy management systems
- » Elements of a industrial plant
- » Modeling
- » Supervision, diagnosis and forecasting.
- » Optimization

Energy service companies (ESCO)

> energy solutions providers, including:
  + designs and implementation of energy savings projects
  + Retrofitting
  + energy conservation
  + energy infrastructure outsourcing
  + power generation and energy supply and risk management
  + efficiency technologies in lighting, HVAC applied to building energy management, industrial energy management, or end users.

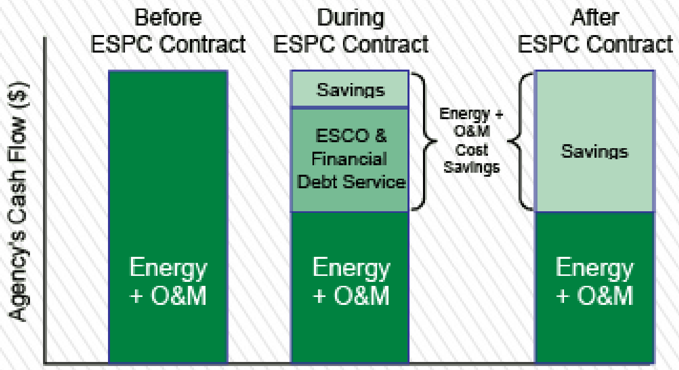
HISTORY

- > **Beginning:** energy crisis of the late 1970s introduce the concept of Time Energy in Texas.
- > The industry grew slowly through the 1970s and 1980s,
- > **The 1990s: deregulation in the U.S. energy markets**
  - + efficiency technologies in lighting, HVAC.
  - + many energy services companies (ESCOs) expand the generation market, building district power plants or cogeneration facilities within efficiency projects.
  - + (BGA, Inc 1996) District Energy Plant business, completing construction on the first 3rd-party owned and operated district cooling plant in Florida.
- > **2000s:**
  - + Enron collapse in 2001 provokes a deregulation efforts
  - + ESCOs in the U.S. grew by 22% in 2006, reaching $3.6 billion, the largest independent energy services company is Ameresco.
- > ESCO market will achieve $66 billion in 2017 !

Preliminary study by energy service companies

> **Energy savings tracking methods**

+ installing **energy conservation measures** (ECMs)
+ Measurement and Verification (M&V) process
  – Use of spreadsheets for calculate the energy savings
+ **International Performance Measurement and Verification** Protocol (IPMVP) is the standard M&V guideline for determining actual savings created by an energy management program.
+ IPMVP has become standard in almost all energy efficiency projects where payments to the contractors is based on the energy savings that will result from the implementation of a variety of ECMs.

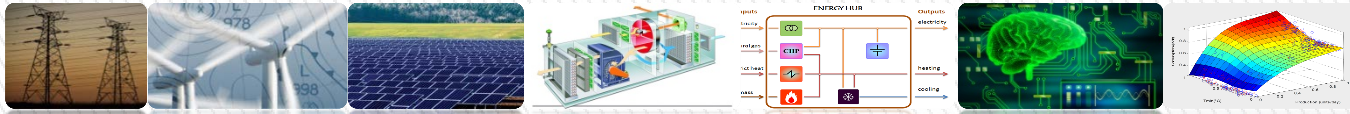


Preliminary study by energy service companies

> IPMVP Options Table: Determining Energy Savings

	Description	Typical Applications
A **Partially Measured Retrofit Isolation**	Savings are determined by partial field measurements of the energy use of the system(s) to which an ECM was applied. Some, but not all, parameters may be stipulated.	Lightin g retrofit where pre - and post-retrofit fixture Wattages are measured. Operating hours of the lights are typically agreed upon.
B **Retrofit Isolation**	Savings are determined by field measurement of the energy use of the systems to which the ECM was applied.	Variable speed drive on a pump. Electricity use is measured by a kWh meter installed on the electrical supply to the pump motor.
C **Whole Facility (Utility Bills)**	Savings are determined by measuring energy use at the utility meter level. Bills may be corrected for weather.	Several ECMs affecting many systems in a building. Utility Bills are used.
D **Calibrated Simulation**	Savings are determined using building simulation. This option is rarely used, and is used primarily when there is no pre -retrofit utility data available.	Multifaceted energy management program affecting many systems in a building but where no base -year data are available.

ECM: energy conservation measures



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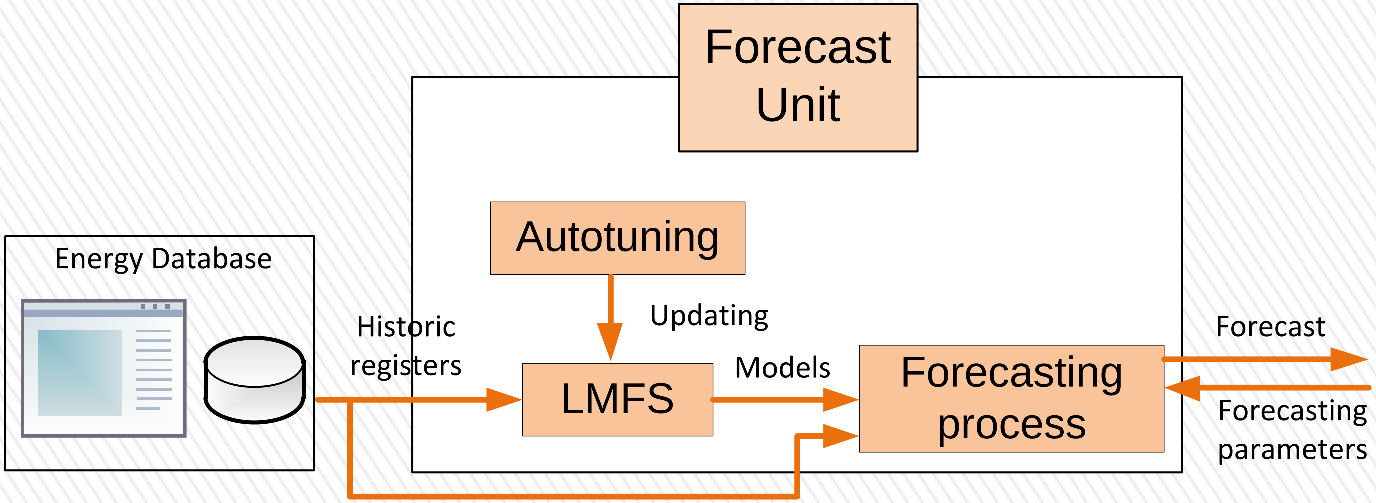
General overview of intelligent energy management system

> This solution is proposed instead of the simple rules applied by the ESCO in order to guarantee the reduction of the energy consumption

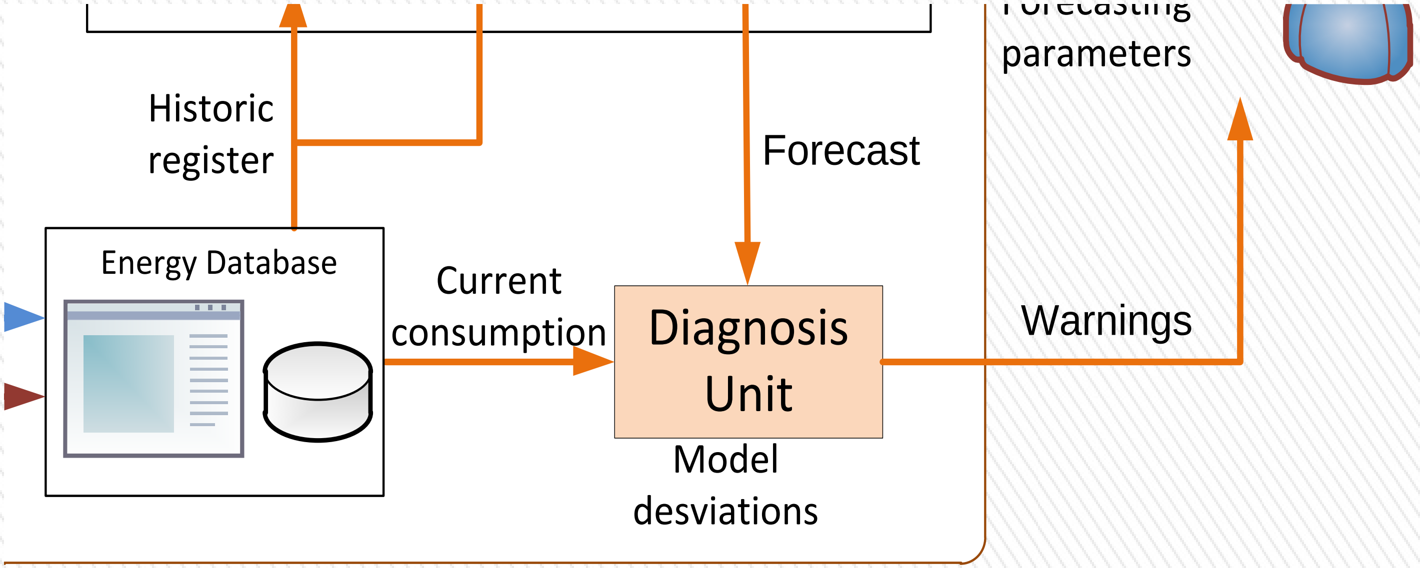
iEMS structure

- Forecasting unit
  - generation of mathematical models for consumers and generators of the plant
    - The models consider different external parameters (i.e., weather data, working days, production process, etc.)



iEMS structure

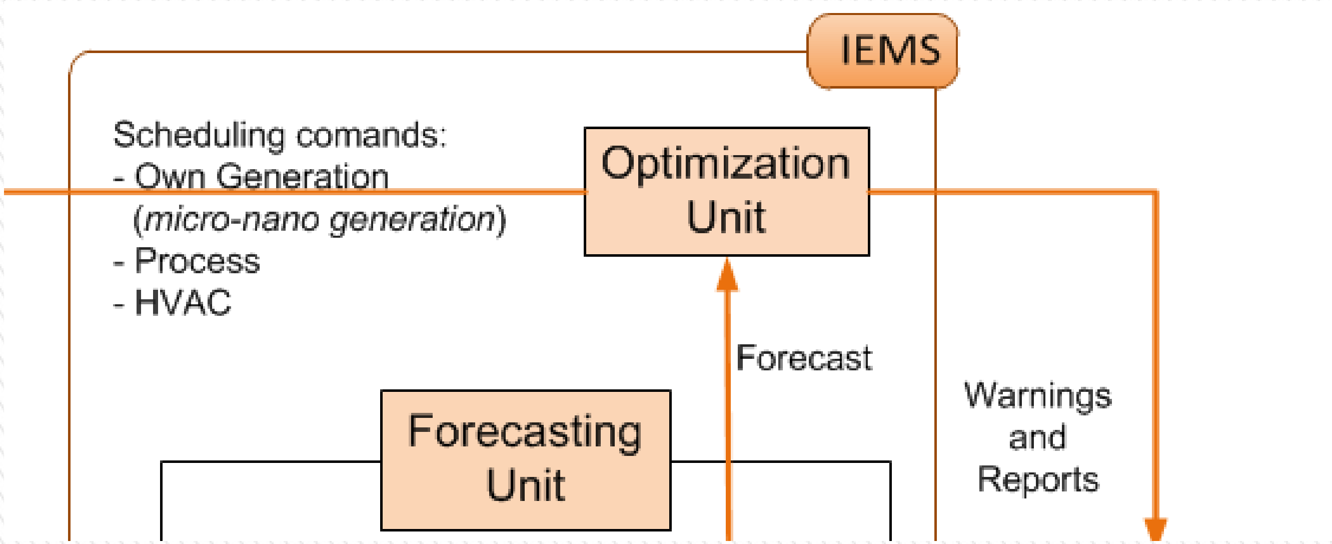
> Diagnosis unit
  + monitors in real time the signal, detecting and diagnosing possible deviations or anomalies in the behavior of the loads or generators.



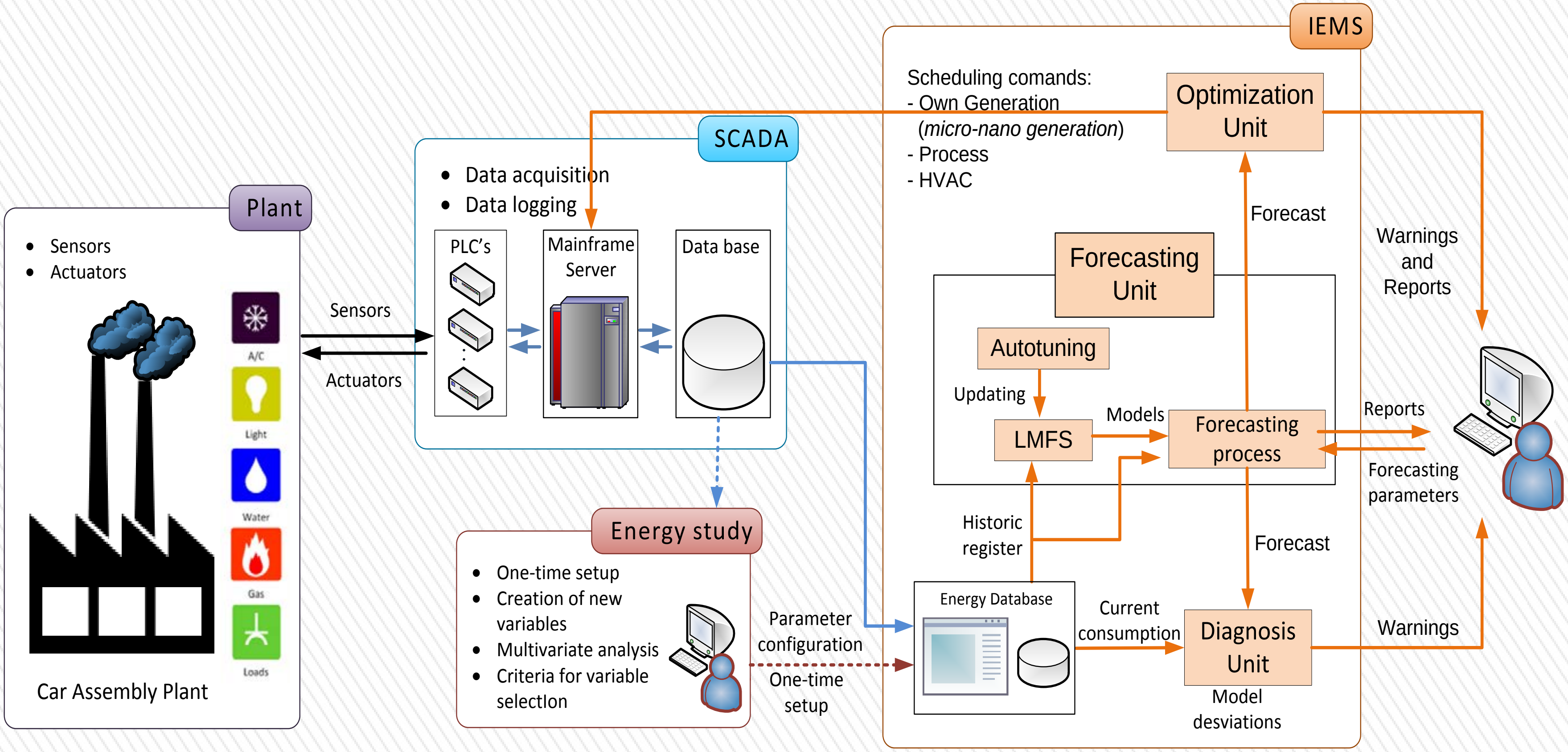
iEMS structure

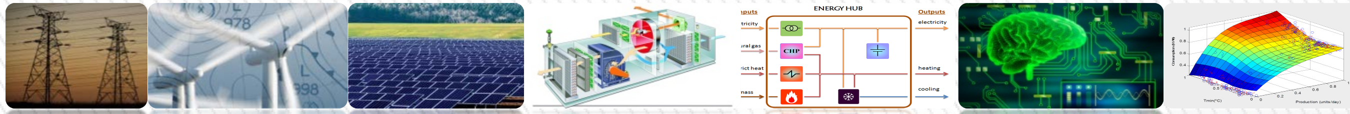
> Optimization unit

+ it works in real time on the consumption´s operation
+ to eliminate any unnecessary expenses and to smooth the consumption profile.
+ It is able to send "warnings", orders of on/off states and orders for the adjustment of the equipment's operation.



iEMS STRUCTURE





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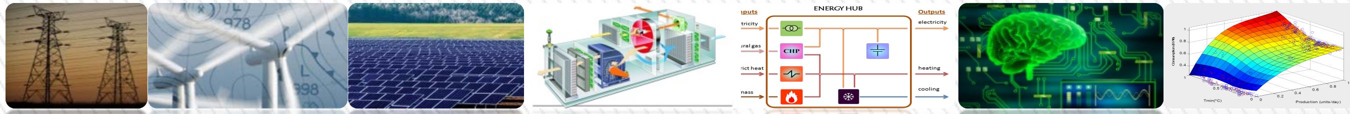


Elements of a industrial plant

> Generation of energy

- The renewable energy technologies
  - Geothermal energy
  - Wind power
  - Solar power and solar thermal
- CHP plant with renewable energy sources (RES)
- Small-scale hydro power
- Cogeneration

> Energy generated

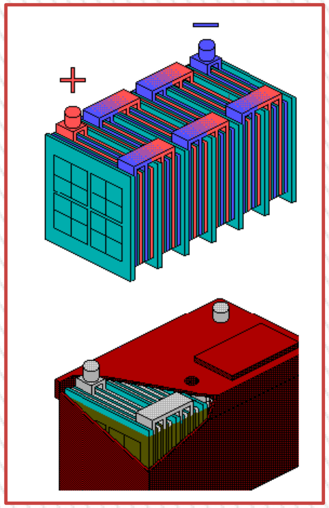
- Cooling energy (technical, comfort)
- Heating energy (technical, comfort)
- Electric energy (lighting, comfort, process)

Elements of a industrial plant

- consumption element
  - Press, motors, lighting, air handling units, chiller, heating's, robots….

- Storage element

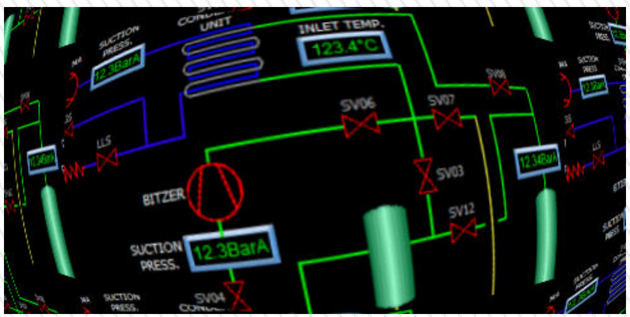
Electricity Storage



Heat Accumulators

Elements of a industrial plant

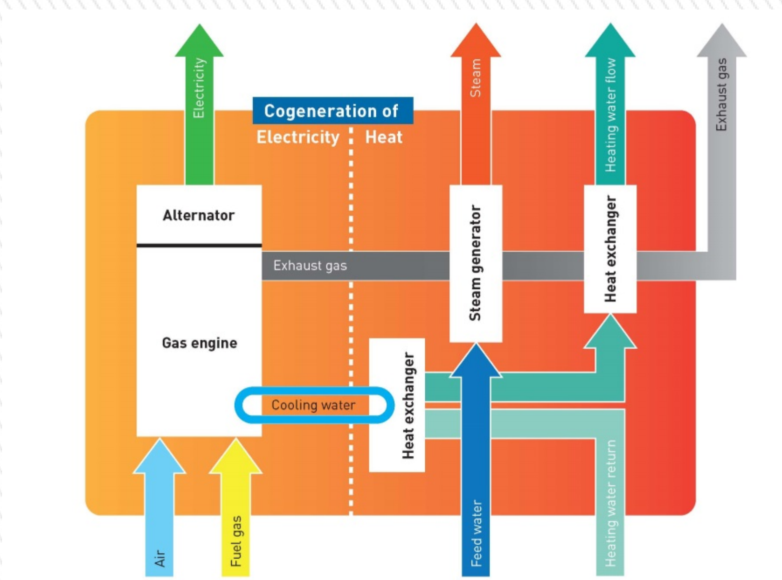
> Control and management systems
  + SCADA – common in industrial applications

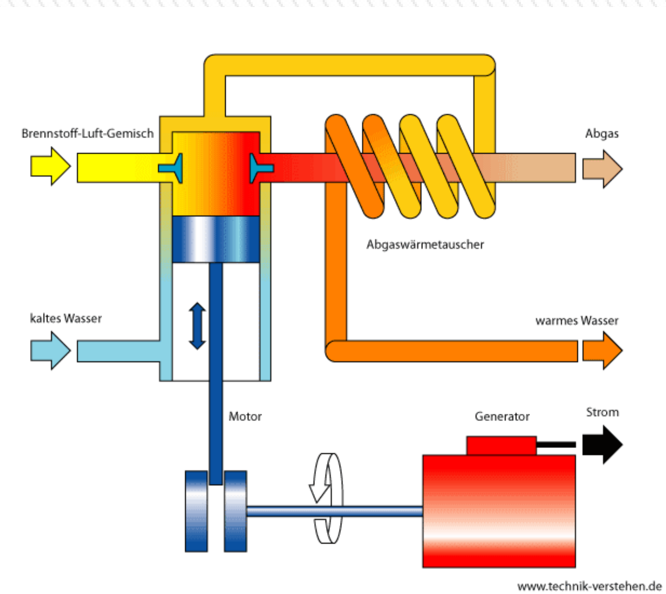


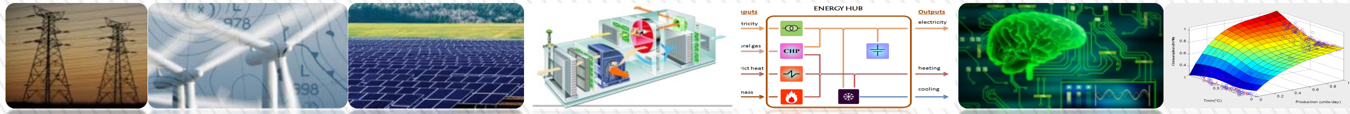
  + Probabilities of improvement in the controls sistems (PID, on off), based on the Measurement and Verification (M&V) process
    - Isolation of heat pipes
    - Variable frequency drives (VFDs)
    - Control,…

Elements of a industrial plant

> Cogeneration: scheme of a gas turbine.







Outline

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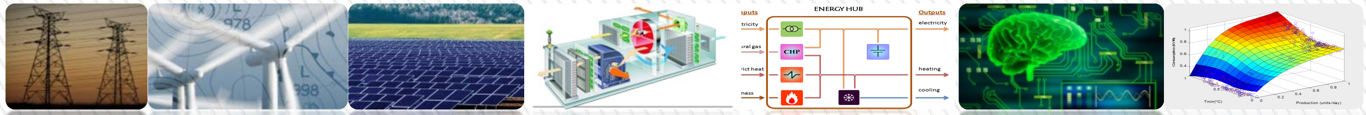
- **Modeling**
- Supervision, diagnosis and forecasting
- Optimization



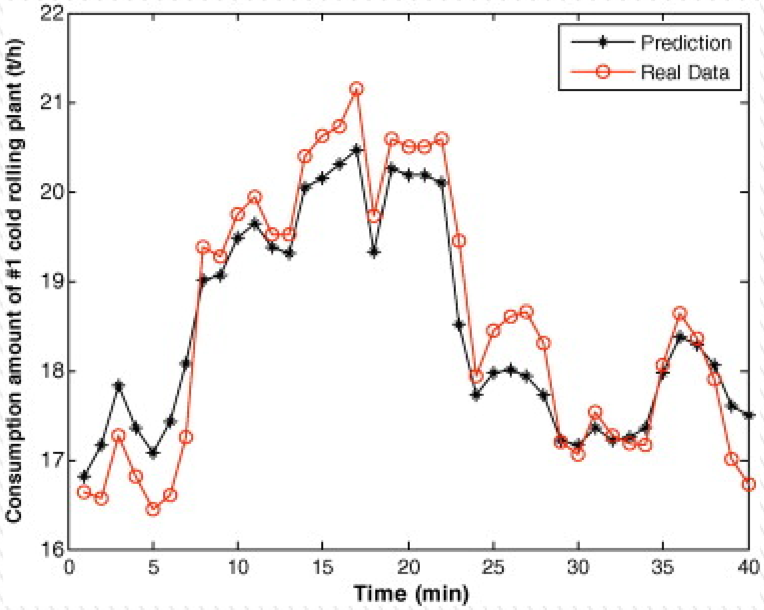
Modeling of loads and generators

> Concept
  + Creation of a mathematical description of the phenomena.
  + Based on parameters or historic behavior.
  + Use *computational intelligent* tools or *physics simulators*.

> Used for
  + **utilities** in generation, transmission and distribution of electricity;
  + **in energy markets** for price forecasting;
  + **in buildings** for HVAC control and optimization.

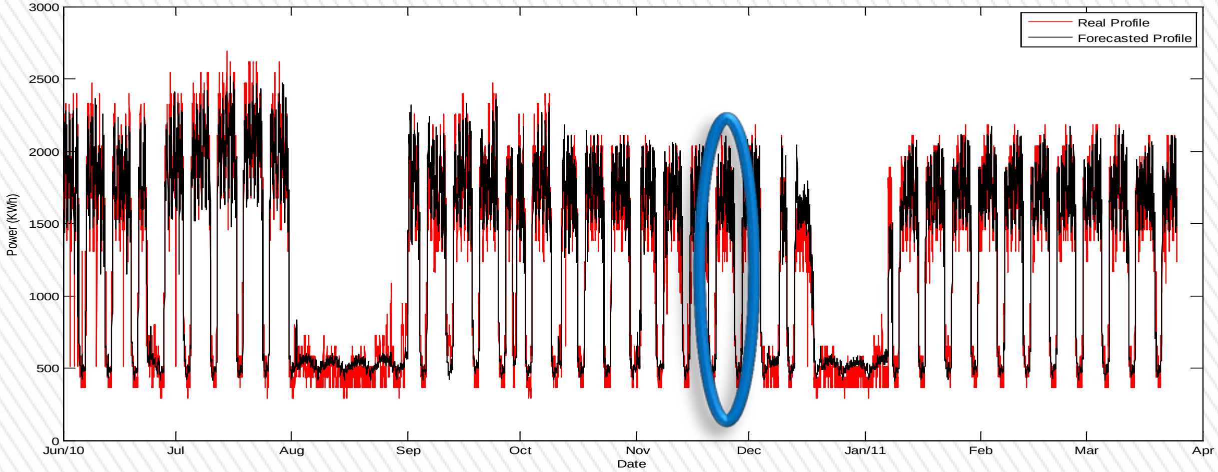
Modeling of loads and generators

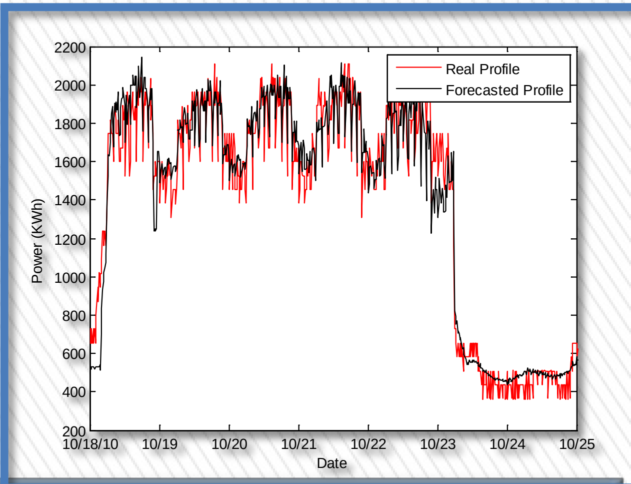
- Expected Results
  - forecasting of the energy demanded or generated.
    - Sample time.
    - Window of the energy prediction.
      - Short term (24 hours ahead)
      - Middle term (1-2 week ahead)
      - long term (1-4 months ahead)



Modeling of loads and generators

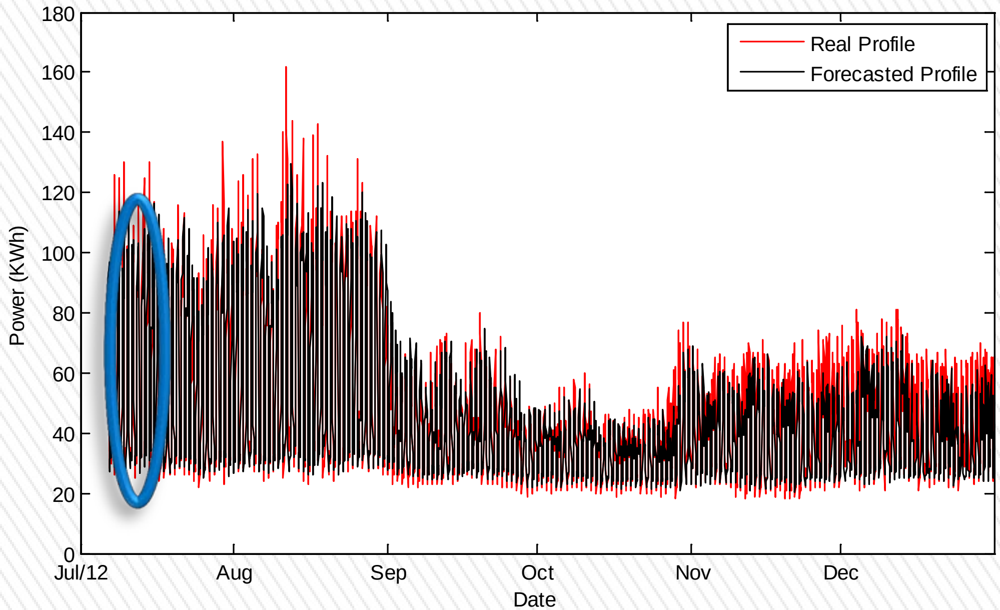
> Expected Results
  + On industrial users
    – Sample time less than 15 min for control action in an optimal time.
    – Short term for control action in an optimal time.
    – Middle term for diagnosis and failures detections.
    – Long term for reports of efficiency.

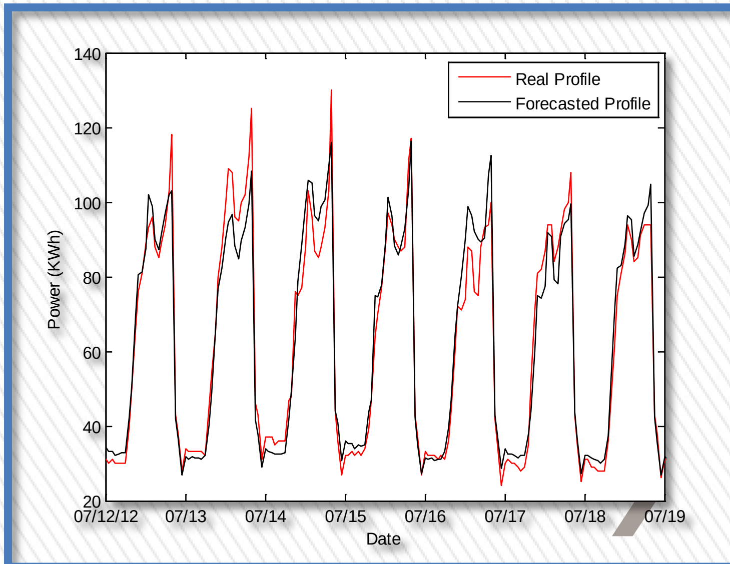




Modeling of loads and generators

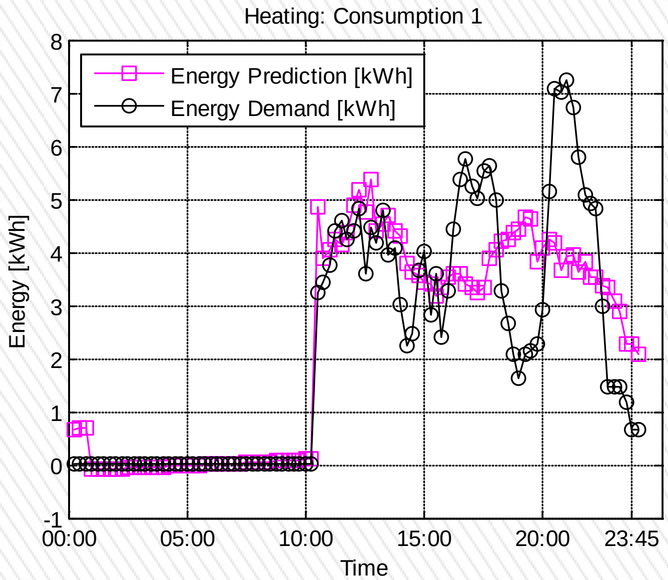
> Expected Results
  + On buildings
    – Sample time less than 1 hour for control action in an optimal time.
    – Short term for control action in an optimal time.
    – Middle term for diagnosis and failures detections.
    – Long term for reports of efficiency.

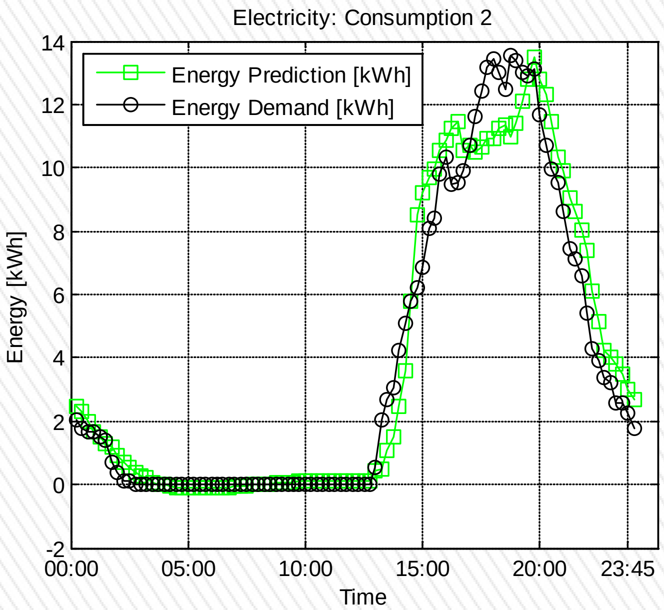




Modeling of loads and generators

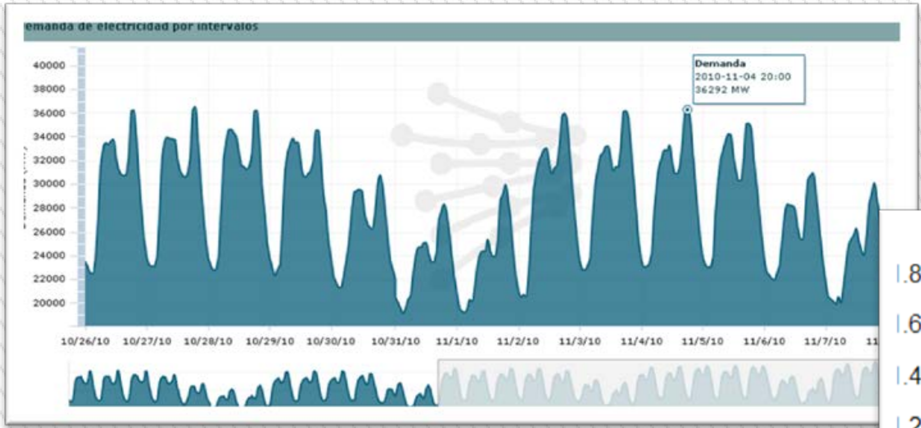
> Expected Results
  - On end users
    - Sample time of 1 hour.
    - Long term for reports of efficiency.

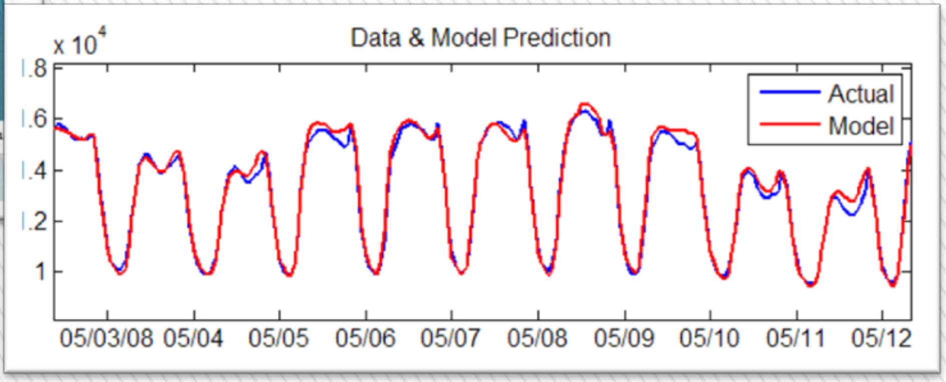


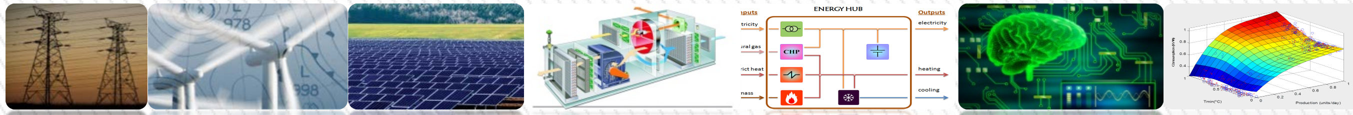


Modeling of loads and generators

> Expected Results
  + On smart grids
    – Sample time of 1 hour.
    – Short term for control action in an optimal time.
    – Middle term for diagnosis and failures detections.
    – Long term for reports of efficiency.







Modeling of loads and generators

> Parametric modeling

- Machinery modeling based on **internal phenomena**.

- Energy conversion units takes some form of energy and transforms it to another, Ex:
  - a generator converting the rotation of its shaft into electrical energy
  - air conditioning equipment converting cold water into cool air.

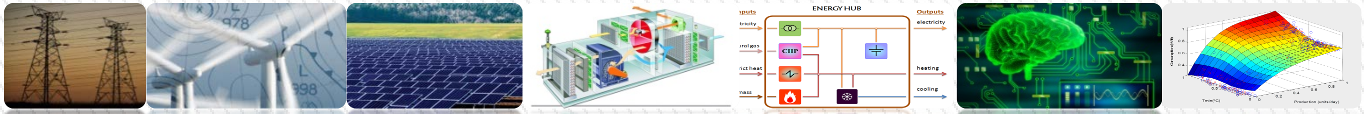
- energy conversion unit takes:
  - a set of inputs
  - internal state variables
  - produces outputs

Modeling of loads and generators

> Parametric modeling

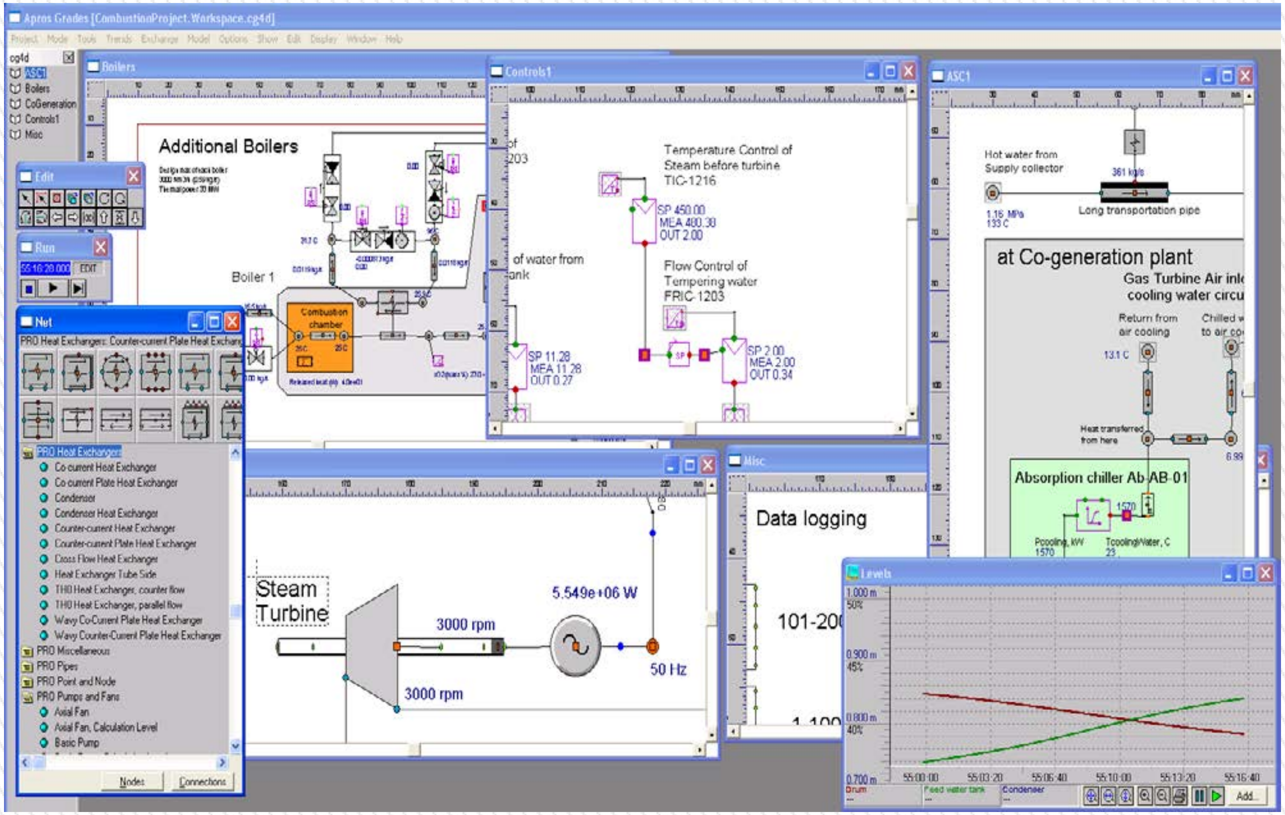
+ Is composed by sub-models
  – The most simple form is a set of constant conversion coefficients from the inputs to the outputs.
  – The internal operations excludes factors as dependence of the coefficients on the plant’s operational state (e.g. summer/winter, day/night) and its dynamics (e.g. start-up of a large absorption chiller can take up to 20 minutes).

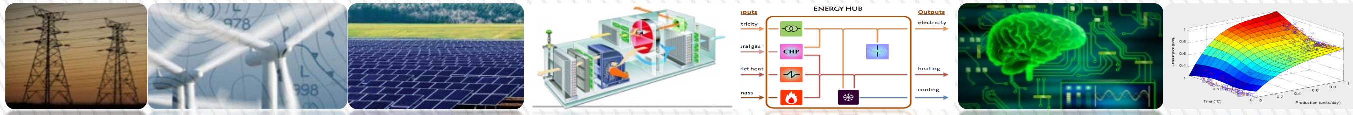
+ Is used to create **on-line models**, which are created using a simulator software and direct measurement of parameters.
+ The on-line models feeding other software's when is impossible capture historic data of the machinery.



Modeling of loads and generators

- Parametric simulator Software's .



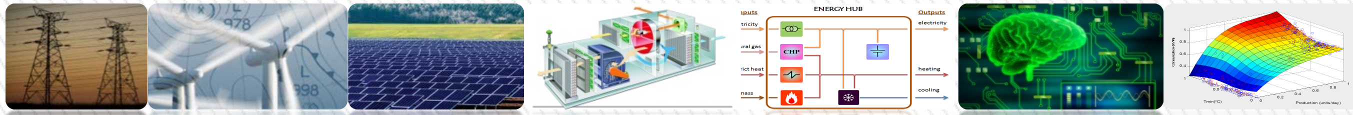


Modeling of loads and generators

> Parametric simulator Software's .

- Steam turbine
- Gas turbine
- Boilers
- Electrical chillers
- Absorption coolers
- Photovoltaic panels
- Pumps
- Valves
- Heat exchangers
- Control and logics modules

	Vendor	Simulator	Primary source of data
1	GSE SYSTEMS	JADE	Vendor website [26]
2	Flowmaster	Flowmaster V7	Vendor website [27]
3	CTI Simulation International	CASSIM	Vendor website [28]
4	Sim Infosystems	ProSimulator and ProGensim	Vendor website [29]
5	SimGenics	<unspecified name>	Vendor website [30]
6	Mathworks	Matlab/Simulink	Vendor website [31]
7	Aspentech	Aspen Plus Dynamics	Software manuals, expert opinion [32], Somers et al. [33]
8	VTT and Fortum	APROS	Software manuals, expert opinion, software website [34]
9	Corys	ALICES	Vendor website [34]
10	TRAX	ProTRAX	Vendor website [36]
11	Endat	Prosim	Vendor website [37]
12	Modelica Association	Modelica	Association website [38]
13	Honeywell	Unisim	Vendor website [39], software evaluation version
14	Andritz	IDEAS	Expert opinion [40]
15	Empresarios Agrupados	EcoSimPro	Software website [41] , software evaluation version



Modeling of loads and generators

> Data Driven Models.

It analyze the collected data of the system and discover the relationships between them without to know the physic behavior of the system.

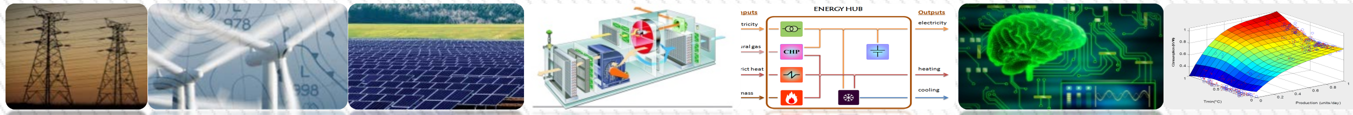
- Hard-computing

  requires a precisely stated analytical model and often a lot of computation time i.e.: ARIMA models, linear regression, polinomic interpolation.

- Soft-computing

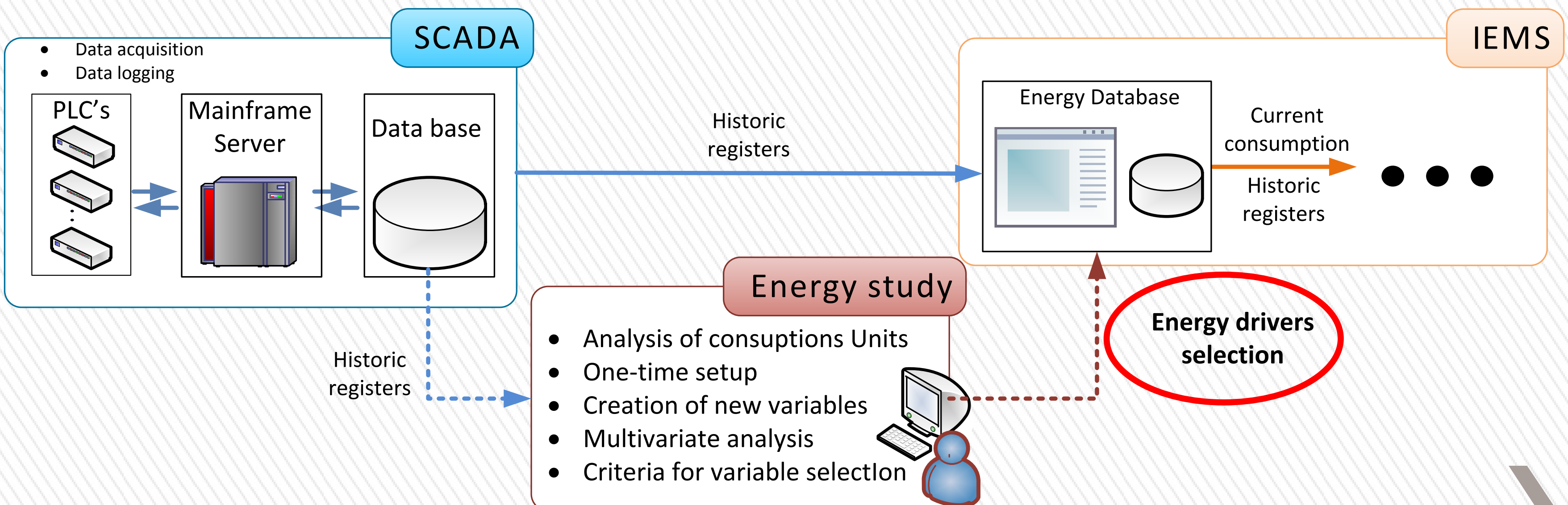
  it is tolerant of imprecision, uncertainty, partial truth, and approximation.

  - probabilistic models (Markov networks, Bayesian models)
  - Bio inspired models:
    - Neural networks
    - fuzzy logic
    - Neuro - fuzzy models
    - genetic algorithms.



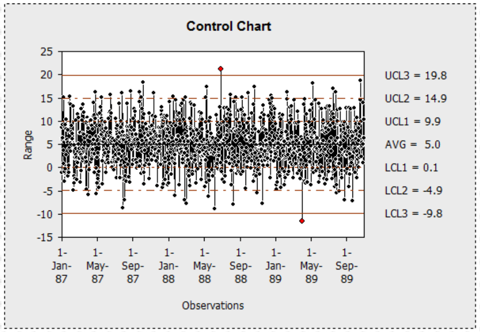
Modeling of loads and generators

- Energy study.
  - Study of the processes and their related energies
  - Definition and selection of the energy drivers of the system: multivariable analysis of possible variables that affect the behavior of the energy consumptions.

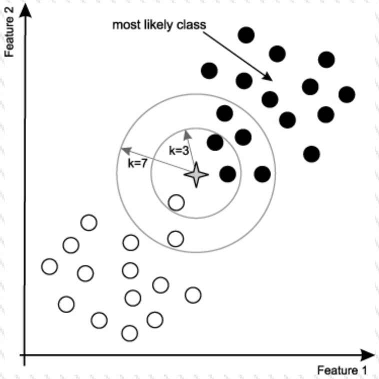


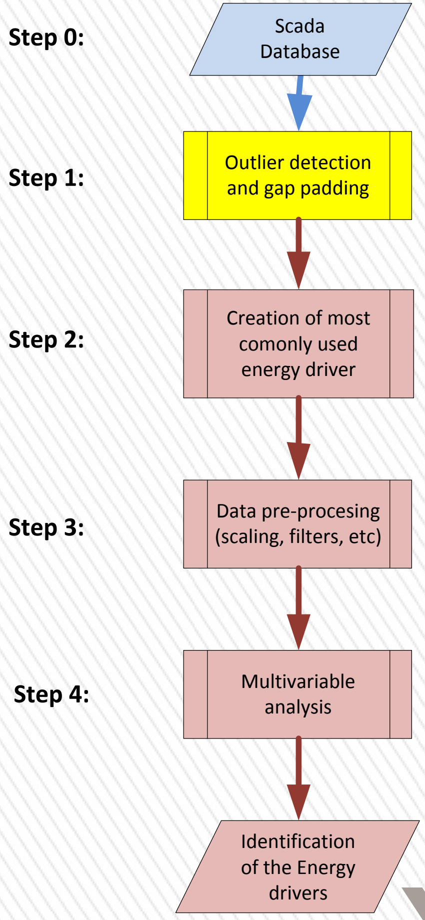
Modeling of loads and generators

> Energy study.
  + Outlier detection and gap padding.
    – 3 sigma threshold for outliers



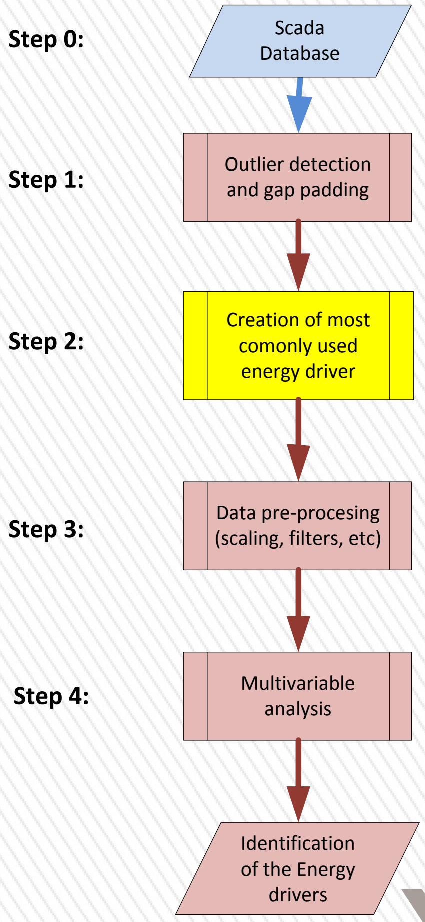
    – KNN for gap padding (non-parametric)





Modeling of loads and generators

- Energy study.
  - Variables commonly used as inputs.
    - Weather variables as temperature, humidity and dew point.
    - Working variables related with scheduled production as: working turn and type of day (holiday or working day).
    - Time variables, such as hour and day of week
    - Delayed variables of the target.

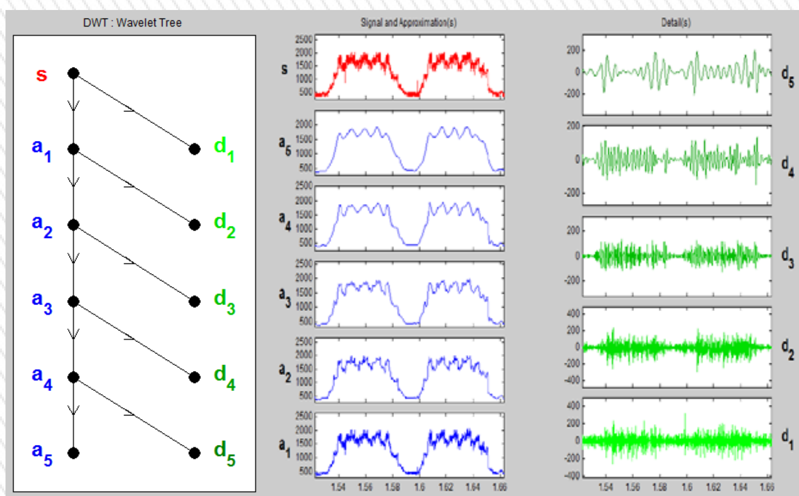


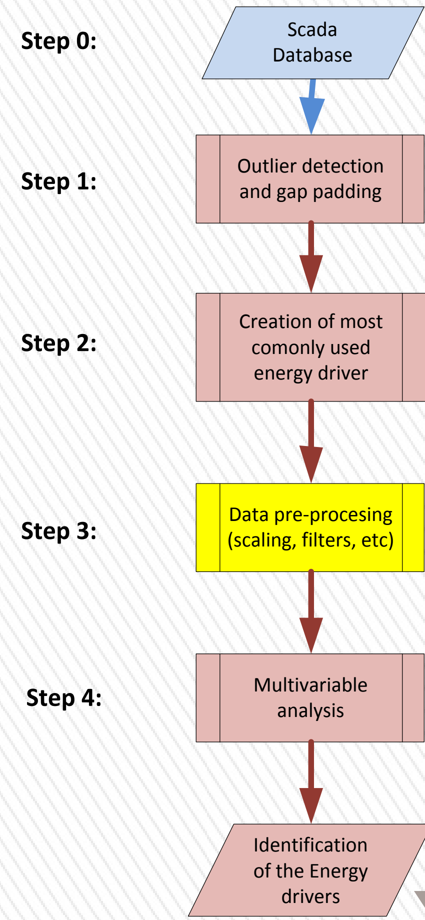
Modeling of loads and generators

- > Energy study.
  - + Preprocessing techniques.
    - – Standardization

$$Z = \frac{\text{value} - \text{mean}}{\text{Std.deviation}}$$

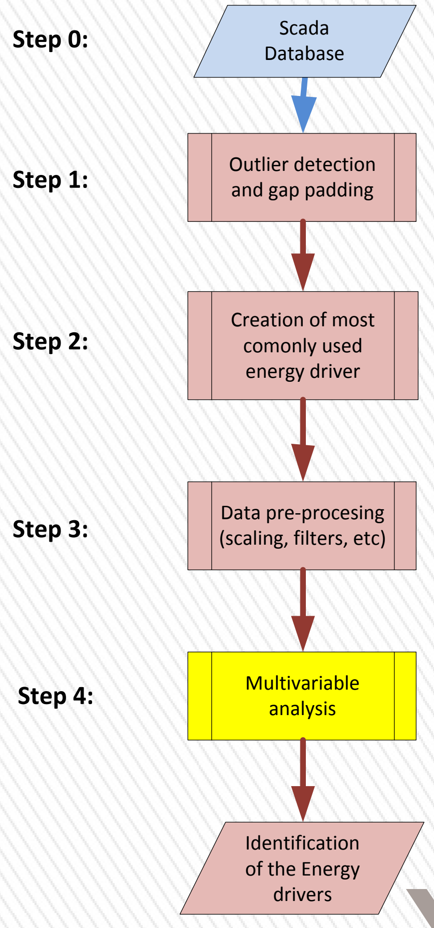
    - – Filtering.
      - » Wavelet transform





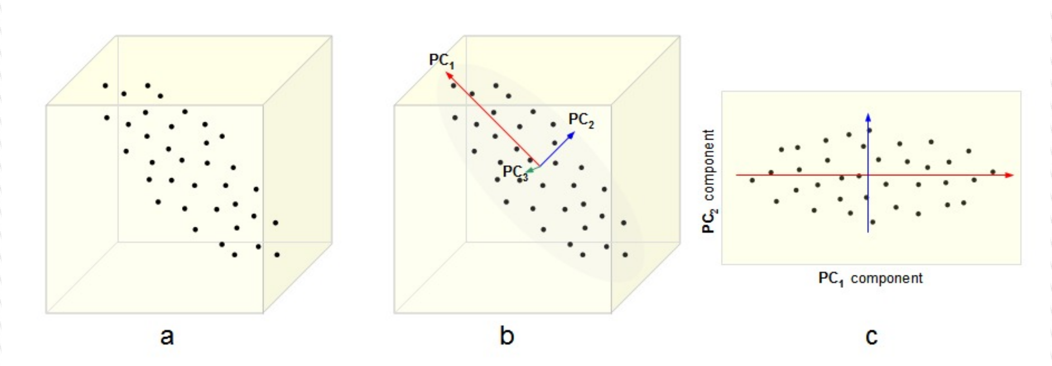
Modeling of loads and generators

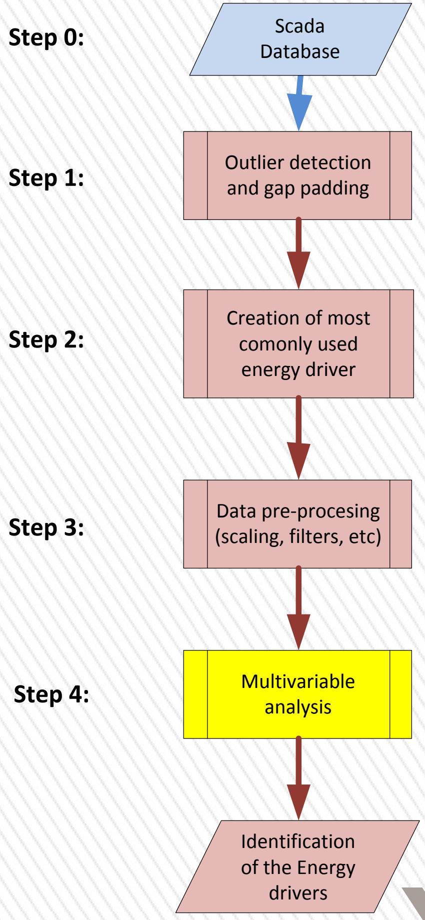
> Energy study.
  + Definition and selection of the inputs.
    – PCA (Principal Component Analysis)
      » Visualization of the information contained in a data matrix
      » Reduction of the dimensionality (feature selection)
      » Extraction of new derived variables (latent), “feature extraction”
      » Smoothing of data (error reduction, avoiding collineality)
      » First phase of the explanatory variables for modeling

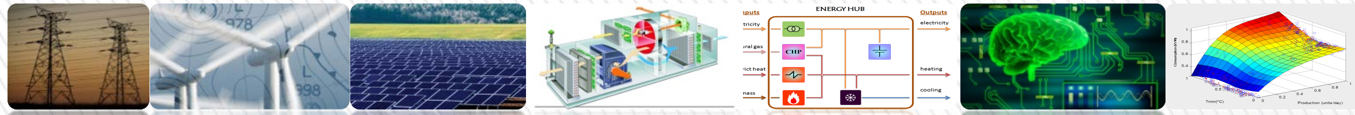


Modeling of loads and generators

- Energy study.
  - Definition and selection of the inputs.
    - PCA analysis
      - Total information contained in the cloud of points: the inertia respect CERO in PC Plane

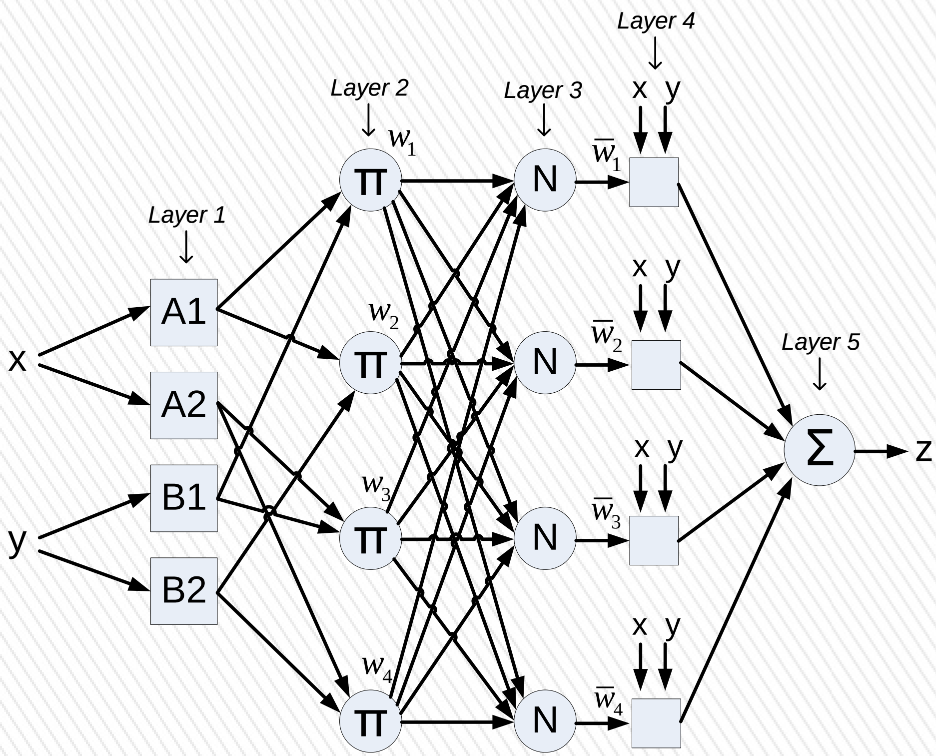




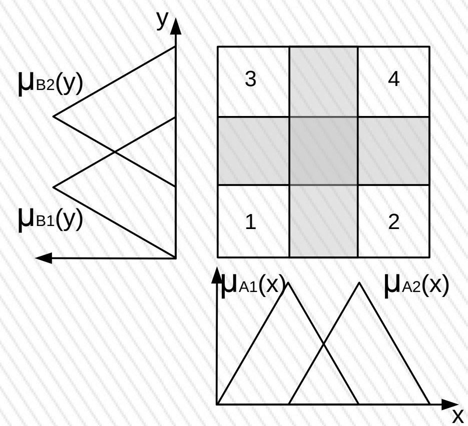


Modeling of loads and generators

ANFIS architecture: two inputs, four if-then rules and one output.



Layer 1: fuzzification – membership function evalution



Layer 2: fuzzy rule evaluation

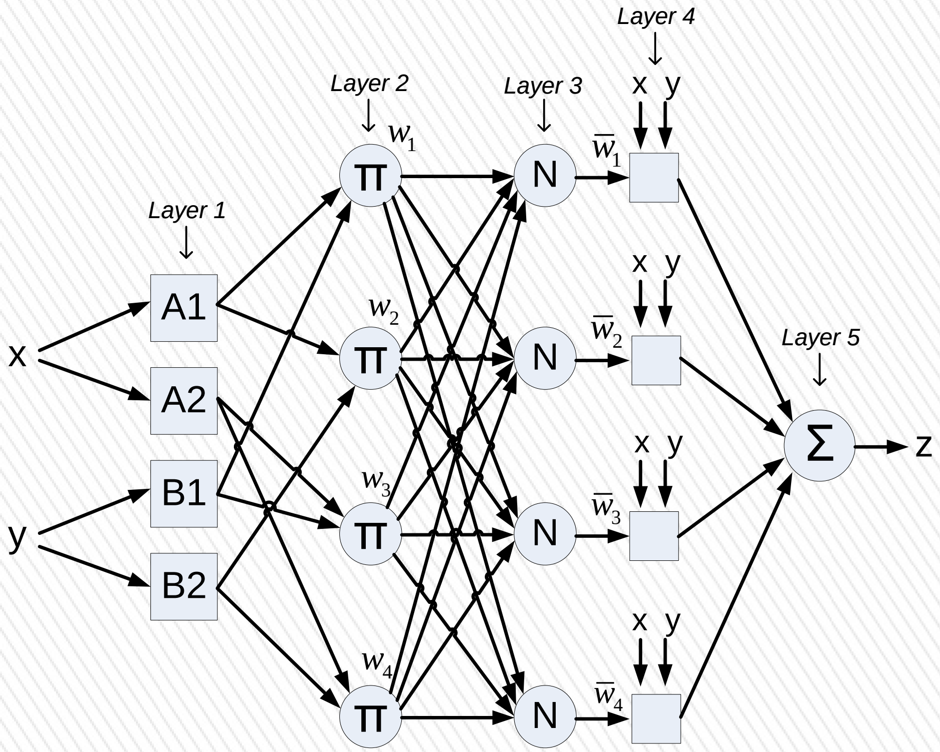
$$\omega_j = \mu_{A_i}(x) \cdot \mu_{B_k}(y), \qquad j = 1, 2, 3, 4. \quad i = 1, 2. \quad k = 1, 2.$$

Layer 3: rule strength calculation

$$\overline{\omega}_j = \frac{\omega_j}{\sum_{i=1}^{N} \omega_i}, \quad N = 4$$

Modeling of loads and generators

ANFIS architecture: two inputs, four if-then rules and one output.



Layer 4: output polinomial evaluation and weighting

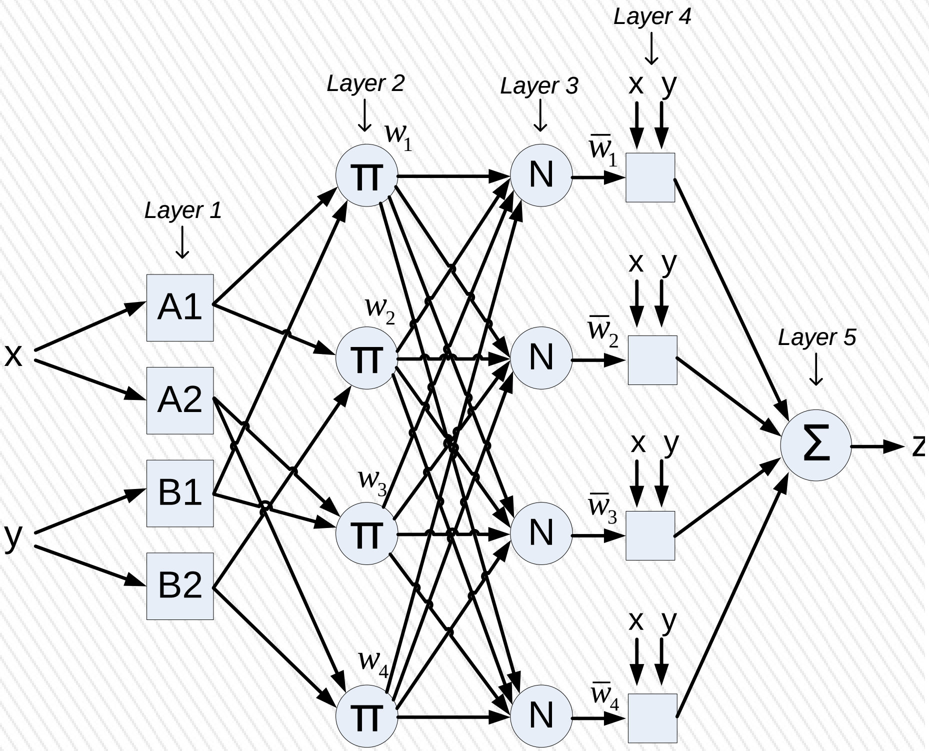
$$z_j \cdot \bar{\omega}_j = \bar{\omega}_j \cdot (p_j x + q_j y + r_j)$$

Layer 5: final output calculation

$$z = \sum_j z_j \cdot \bar{\omega}_j$$

Modeling of loads and generators

ANFIS architecture: two inputs, four if-then rules and one output.



Rules

$$if\ x \in A_1 \wedge y \in B_1 \Rightarrow z_1 = p_1 x + q_1 y + r_1$$
$$if\ x \in A_1 \wedge y \in B_2 \Rightarrow z_2 = p_2 x + q_2 y + r_2$$
$$if\ x \in A_2 \wedge y \in B_1 \Rightarrow z_3 = p_3 x + q_3 y + r_3$$
$$if\ x \in A_2 \wedge y \in B_2 \Rightarrow z_4 = p_4 x + q_4 y + r_4$$

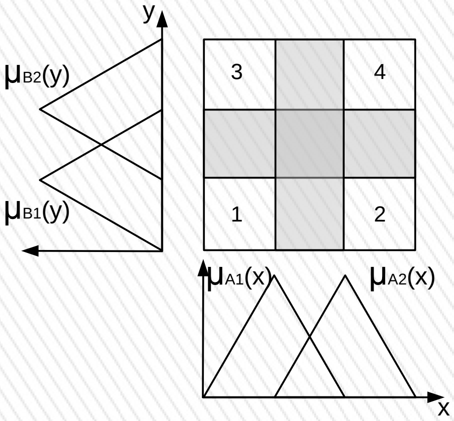
Linguistic interpretation

$$if\ production\ (x) is\ low (A_1)\ \&\ time\ (y) is\ morning\ (B_1) \Rightarrow consumption_1 = p_1 x + q_1 y + r_1$$
$$if\ production\ (x) is\ low (A_1)\ \&\ time\ (y) is\ night\ (B_2) \Rightarrow consumption_2 = p_2 x + q_2 y + r_2$$
$$if\ production\ (x) is\ high\ (A_2)\ \&\ time\ (y) is\ morning\ (B_1) \Rightarrow consumption_3 = p_3 x + q_3 y + r_3$$
$$if\ production\ (x) is\ high\ (A_2)\ \&\ time\ (y) is\ night\ (B_2) \Rightarrow consumption_4 = p_4 x + q_4 y + r_4$$

Modeling of loads and generators

Training algorithms

- ❑ Antecedent parameters:
  - ➢ Back propagation(BP)
  - ➢ Evolutive algorithms (PSO, GA)
- ❑ Consequent parameters:
  - ➢ Square least(LS)



$$if\ x \in A_1 \wedge y \in B_1 \Rightarrow z_1 = p_1 x + q_1 y + r_1$$
$$if\ x \in A_1 \wedge y \in B_2 \Rightarrow z_2 = p_2 x + q_2 y + r_2$$
$$if\ x \in A_2 \wedge y \in B_1 \Rightarrow z_3 = p_3 x + q_3 y + r_3$$
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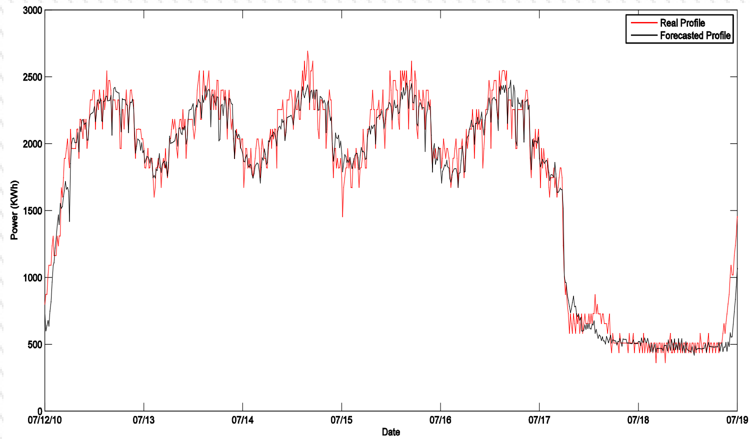
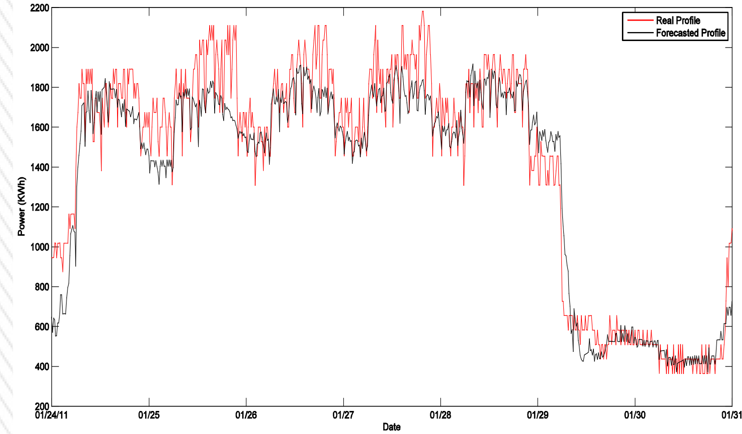
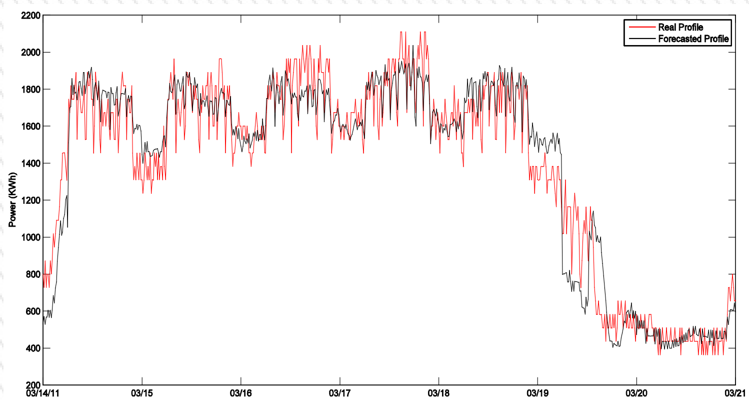
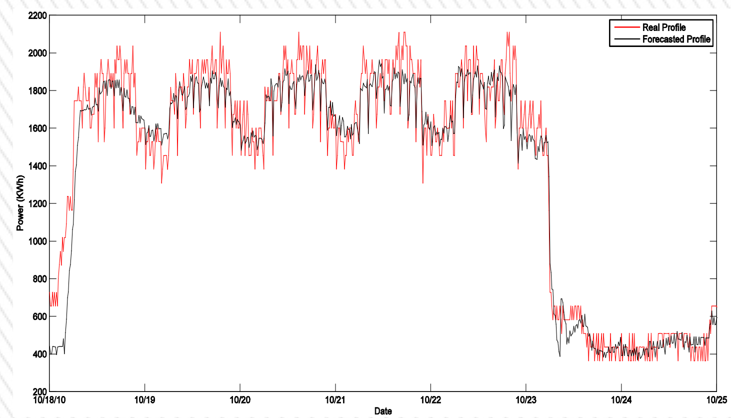
Modeling of loads and generators









Outline

» Energy service companies (ESCO)

» Intelligent energy management systems

» Elements of a industrial plant

» modeling

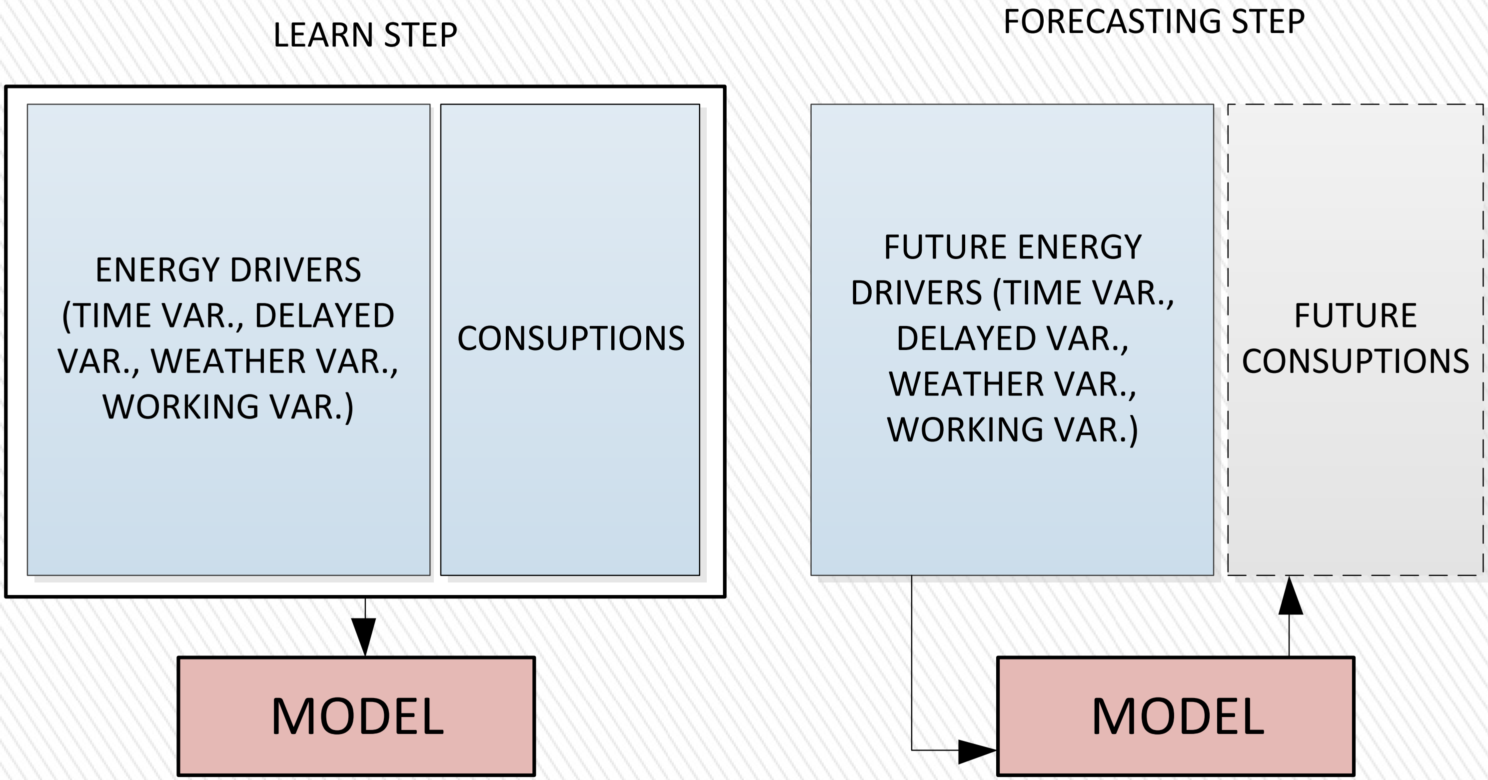
» **Supervision, diagnosis and forecasting**

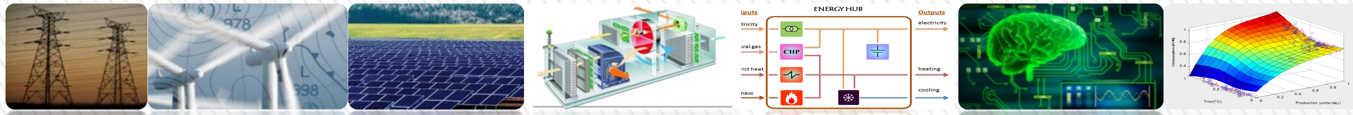
» Optimization

Supervision, diagnostic y forecasting

» Forecasting process.

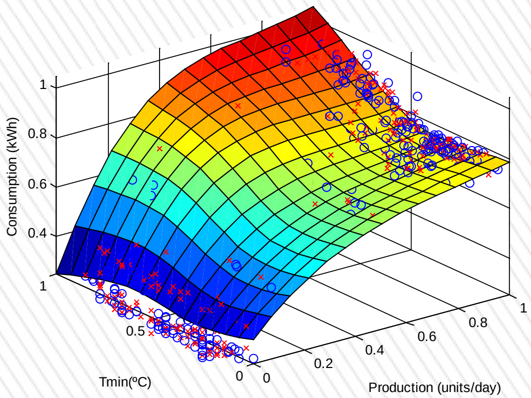
> Steps.



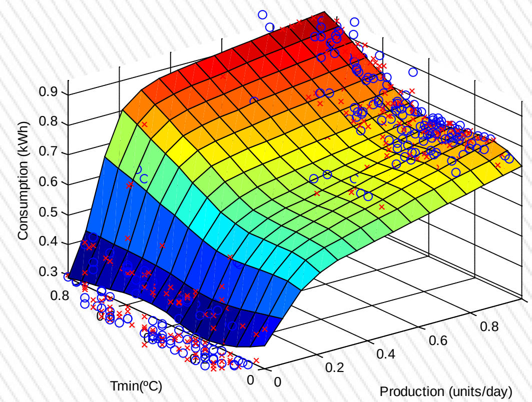


Supervision, diagnostic y prediction

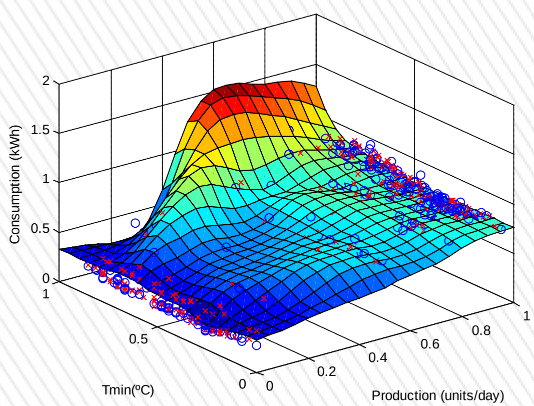
ANFIS model



G-ANFIS model



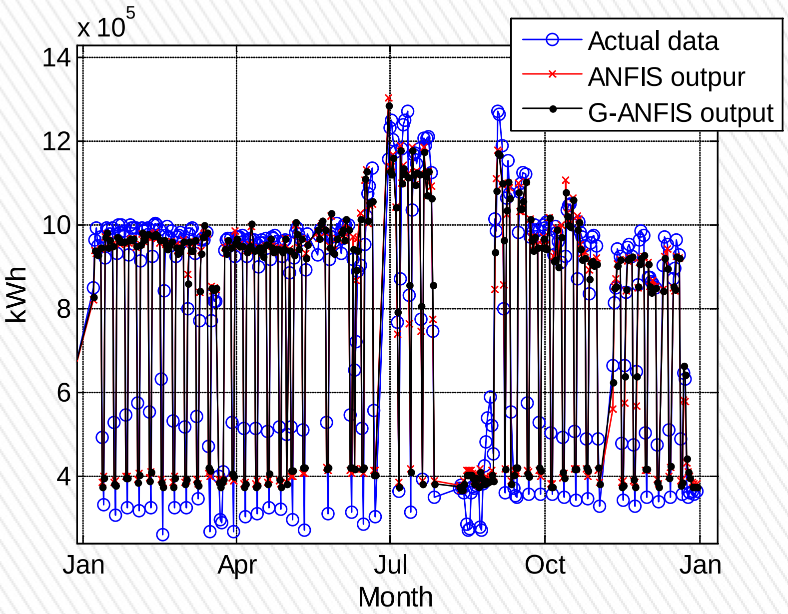
NN model

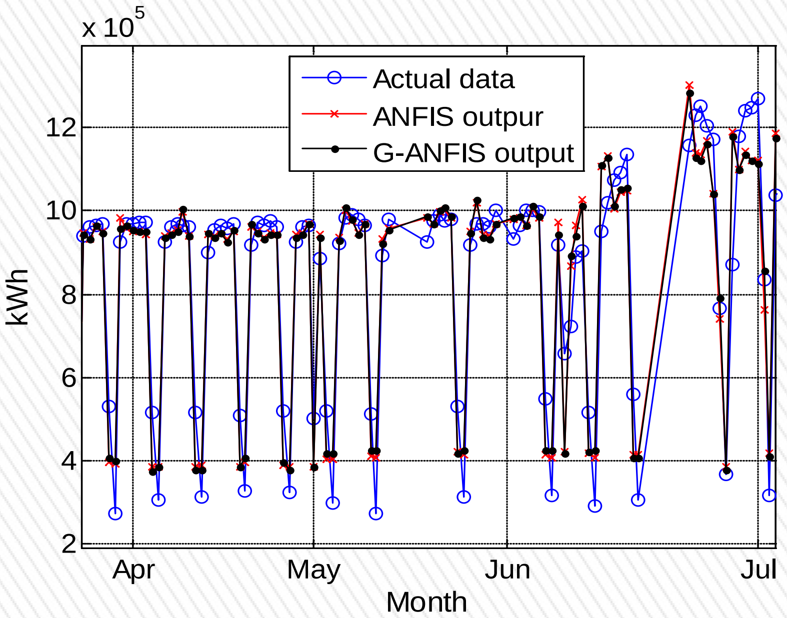


	Training RMSE	Checking RMSE
ANFIS	0,0604	0,0622
NN	0,0646	0,0734
G-ANFIS	0,0612	0,0620

Table 1. Comparison of RMSE obtained from different models and training algorithms.

Supervision, diagnostic y prediction

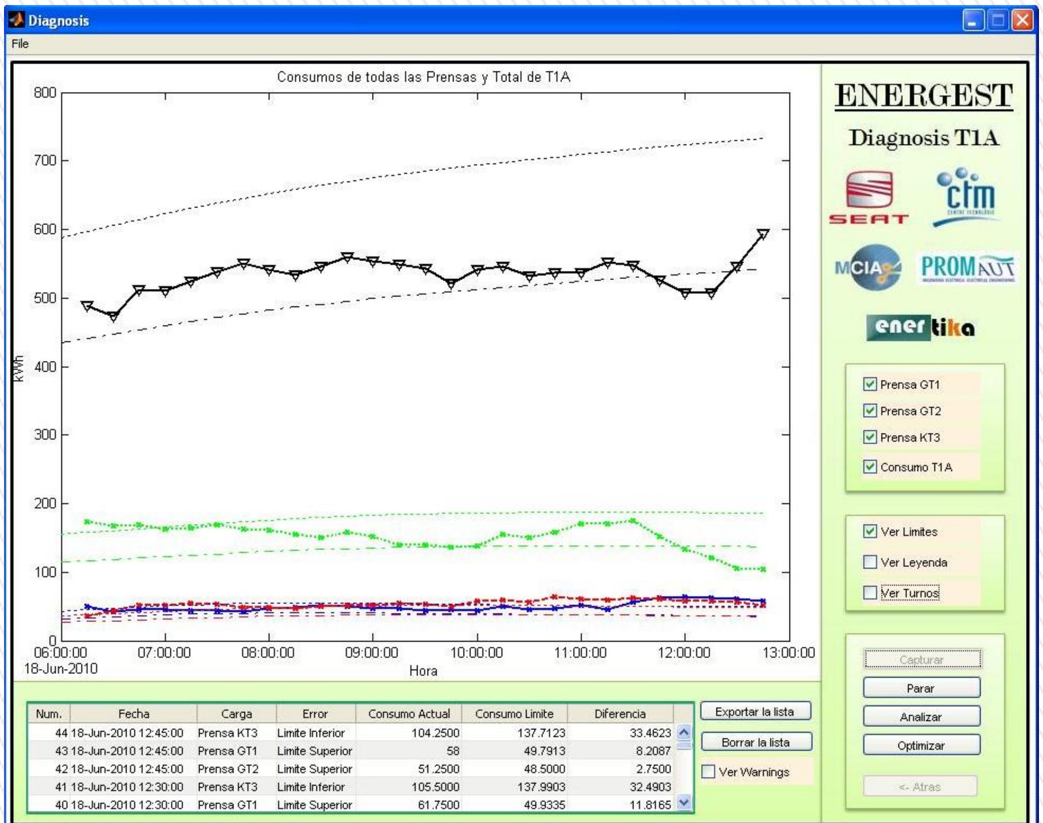




Supervision, diagnostic y prediction

> Diagnostic:

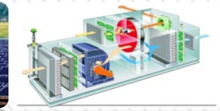
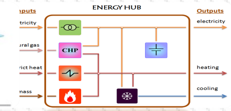
+ Anomalies detection based in a comparison between the predicted behavior and the real behavior.

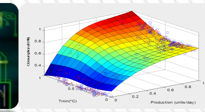


Outline

- Energy service companies (ESCO)
- Intelligent energy management systems
- Elements of a industrial plant
- Load and modeling
- Supervision, diagnosis and forecasting
- **Optimization**



Optimization

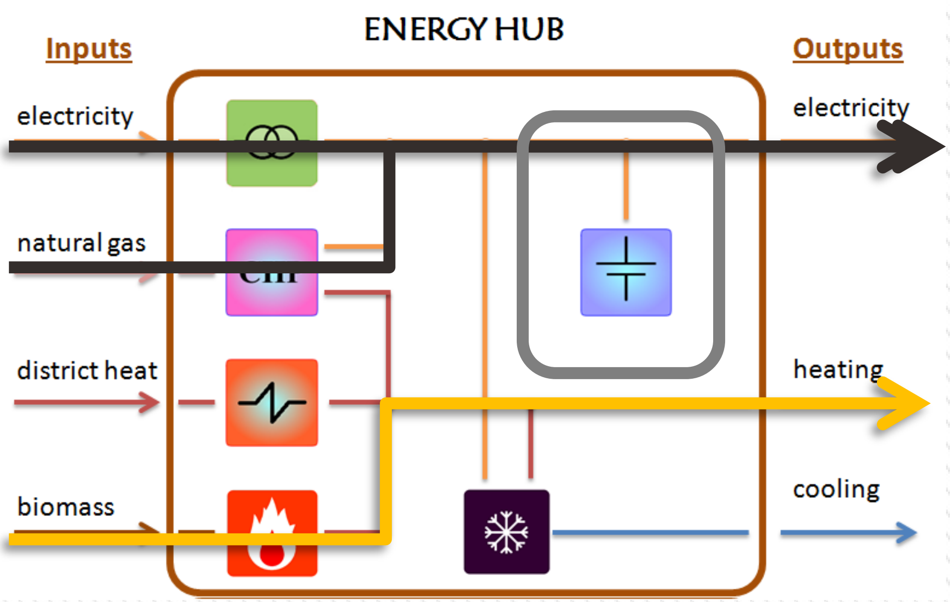
> Concept:
  + refers to problems stated as maximization or minimization of a linear function subject to constraints that are linear equalities and inequalities.

> Objectives in energy applications:
  + optimize the energy flow in the plant
  + minimizing the operation cost , CO2 emissions, energy peaks demand

> Actions:
  + mathematically formulation of the producer-consumer system based on the energy hub concept, analysing the different energy carriers inside the plant.
  + Run a optimization algorithm searching for the best local configuration (connections) between energy producers and load consumers
  + This algorithms that a fitness functions that penalize the costs and emissions.

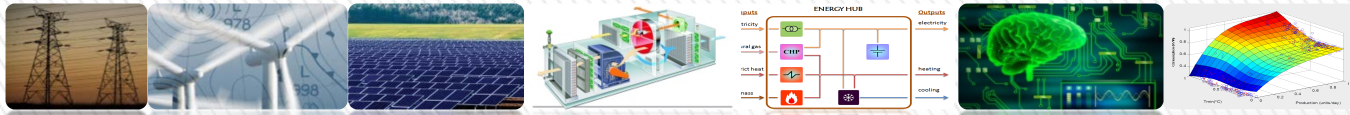
Energy Hub Concept

"… An ENERGY HUB is considered as a unit where multiple energy carriers can be converted, conditioned and stored. It represents an interface between different energy infrastructures and/or loads. It consumes power at their input ports and provide certain required energy services at the output ports…" *[M. Geidl, 2007]*



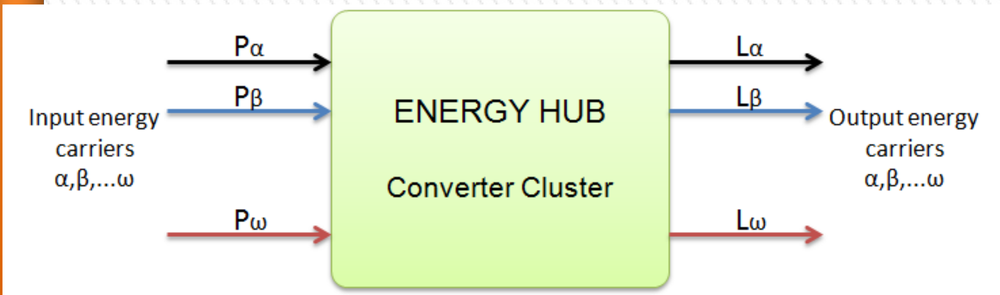
An Energy Hub can contain the following elements:

- ❑ Direct connections
- ❑ Energy converters
- ❑ Storage systems



Energy Hub Concept

- This general modeling concept enables the description of power transmission in the same way as conversion.

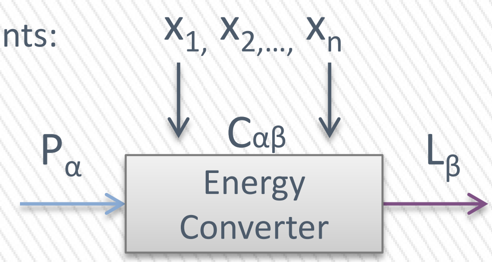


- Converter Clusters (Coupling Matrix) of the System:

$$\begin{bmatrix} L_\alpha \\ L_\beta \\ \vdots \\ L_\omega \end{bmatrix} = \begin{bmatrix} C_{\alpha\alpha} & C_{\beta\alpha} & \cdots & C_{\omega\alpha} \\ C_{\alpha\beta} & C_{\beta\beta} & \cdots & C_{\omega\beta} \\ \vdots & \cdots & \ddots & \vdots \\ C_{\alpha\omega} & C_{\beta\omega} & \cdots & C_{\omega\omega} \end{bmatrix} * \begin{bmatrix} P_\alpha \\ P_\beta \\ \vdots \\ P_\omega \end{bmatrix}$$

$$\alpha, \beta, ..., \omega \in \mathcal{E} = \{electricity, natural\ gas, heat, ...\}$$

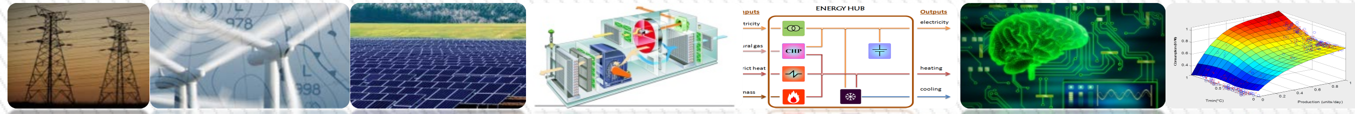
- Coefficients:



$$L_\beta = C_{\alpha\beta} * P_a$$

$$C_{\alpha\beta} = f(x_1, x_{2,...,} x_n)$$

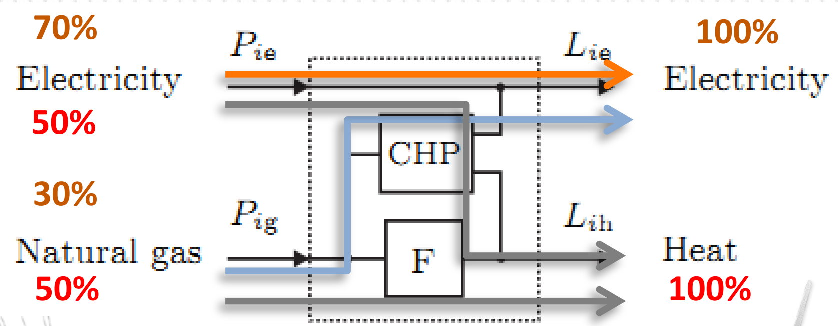
Type of coupling	Coupling factor	Energy carriers
Lossless transmission	$c_{\alpha\beta} = 1$	$\alpha = \beta$
Lossy transmission	$0 < c_{\alpha\beta} \leq 1$	$\alpha = \beta$
Lossless conversion	$c_{\alpha\beta} = 1$	$\alpha \neq \beta$
Lossy conversion	$0 < c_{\alpha\beta} \leq 1$	$\alpha \neq \beta$
No coupling	$c_{\alpha\beta} = 0$	any α,β

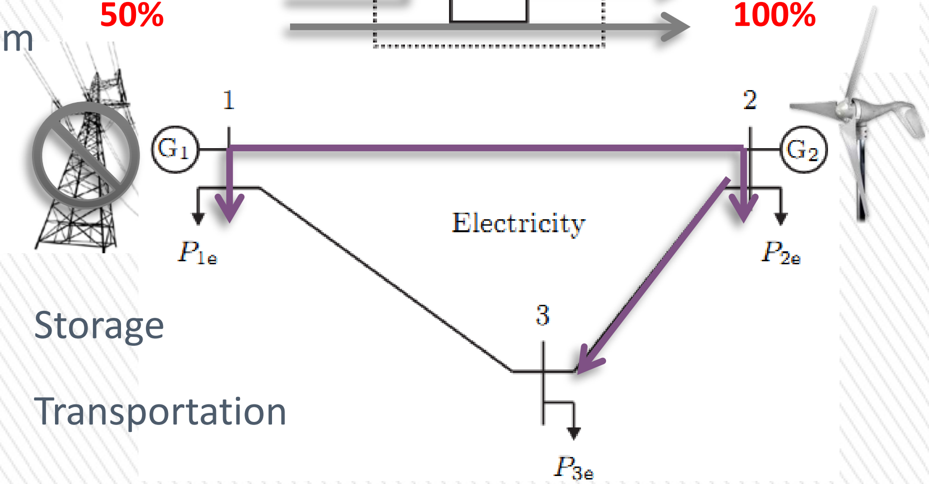


Energy Hub Concept

The benefits of an Energy Hub are:

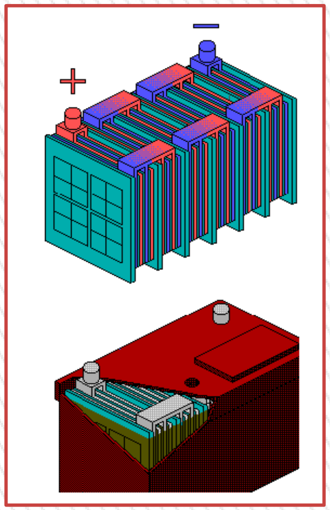
- The reliability of the energy supply
- Flexibility of satisfying the energy demand
- Optimization of the energy use in the system
- Advantages of the different energy forms





- Storage
- Transportation

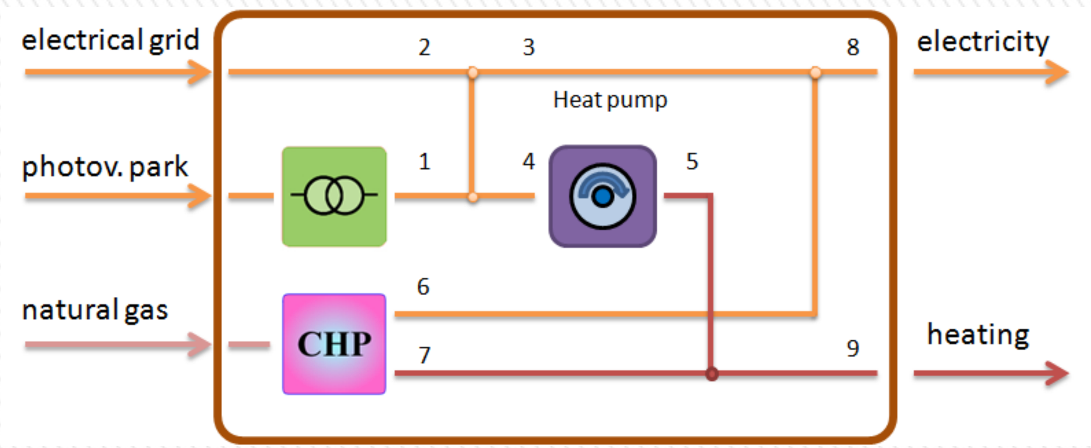
Electricity Storage



Heat Accumulators

[G. Koeppel, "Reliability Considerations of Future Energy Systems: Multi-Carrier Systems and the Effect of Energy Storage." PhD thesis, Power Systems Laboratory, ETH Zurich, 2007]

Energy Hub Concept - Formulation



$$P_1 = P_{pv}\eta_{tr}$$

$$P_2 = P_{grid}$$

$$P_3 = P_{grid}v_2 + P_1 v_1$$

$$P_4 = P_{grid}(1-v_2) + P_1(1-v_1)$$

$$P_5 = P_4\eta_{pump}$$

$$P_6 = P_{gas}\eta_{el}^{CHP}$$

$$P_7 = P_{gas}\eta_{heat}^{CHP}$$

$$P_8 = P_3 + P_6$$

$$P_9 = P_7 + P_5$$

$$P_{el}^{out} = P_{grid}v_2 + P_{gas}\eta_{el}^{CHP} + P_{pv}\eta_{tr}v_1$$

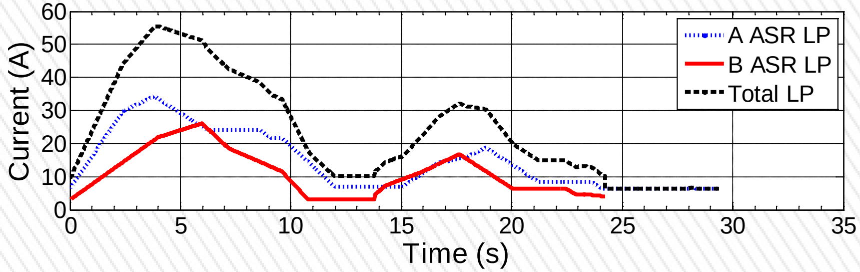
$$P_{heat}^{out} = P_{grid}\eta_p(1-v_2) + P_{gas}\eta_{heat}^{CHP} + P_{pv}\eta_{tr}\eta_p(1-v_1)$$

Inputs | Coupling Matrix | Outputs

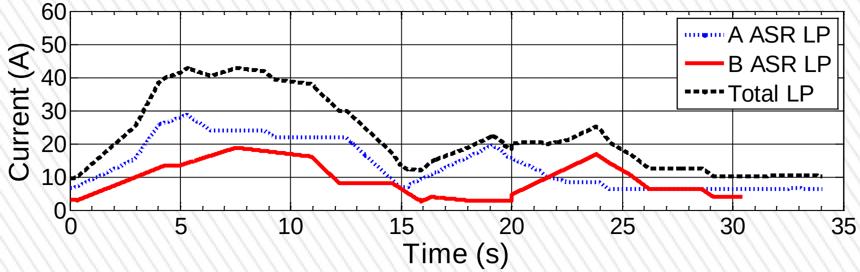
$$\begin{bmatrix} P_{el}^{out} \\ P_{heat}^{out} \end{bmatrix} = \begin{bmatrix} v_2 & \eta_{tr}v_1 & \eta_{el}^{CHP} \\ \eta_{pump}(1-v_2) & \eta_{pump}\eta_{tr}(1-v_1) & \eta_{heat}^{CHP} \end{bmatrix} * \begin{bmatrix} P_{grid}^{in} \\ P_{pv}^{in} \\ P_{gas}^{in} \end{bmatrix}$$

Energy Hub Concept - Formulation

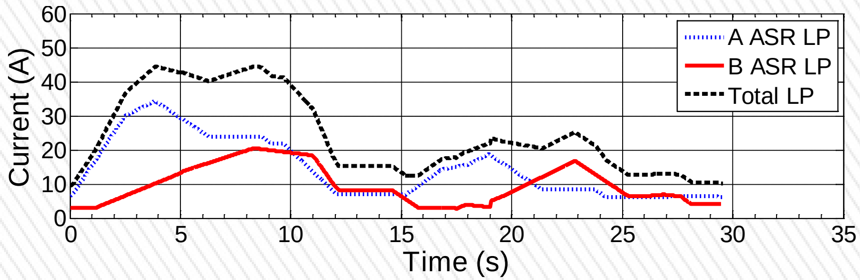
Optimization over the power comsuption



Original

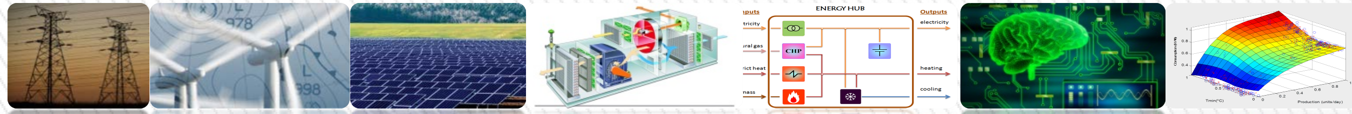


GA



Multiobjetive GA

INCREASE OF AUTOMOTIVE CAR INDUSTRY COMPETITIVENESS THROUGH AN INTEGRAL AND ARTIFICIAL INTELLIGENCE DRIVEN ENERGY MANAGEMENT SYSTEM



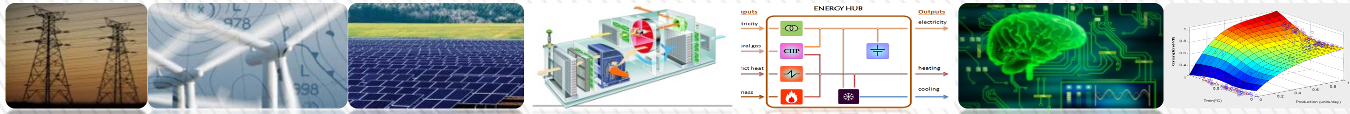
EUROENERGEST PROJECT

» Problems to be solved.

- Increase of competitiveness of car manufacturers by means of energy efficiency management improvement systems
- To reduce energy costs and Climate change
- To be an example in energy efficiency so as to industrial sector and International policy

» Objectives

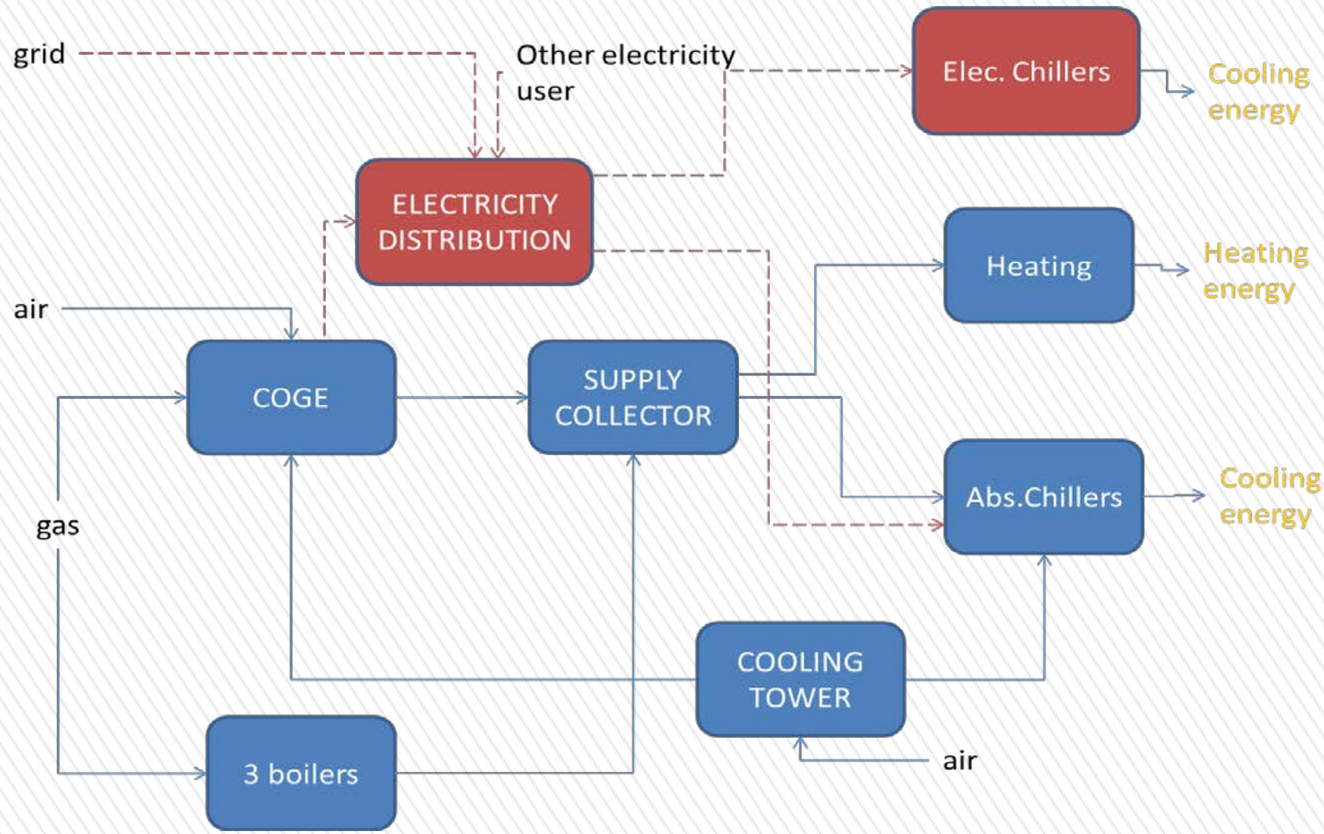
- Optimize the energy performance of the automotive industry
- Model patterns of energy consumption & Environment impact
- Intelligent Energy Management System (iEMS) for energy optimization
- Test in a real situation within a large car manufacturer facility

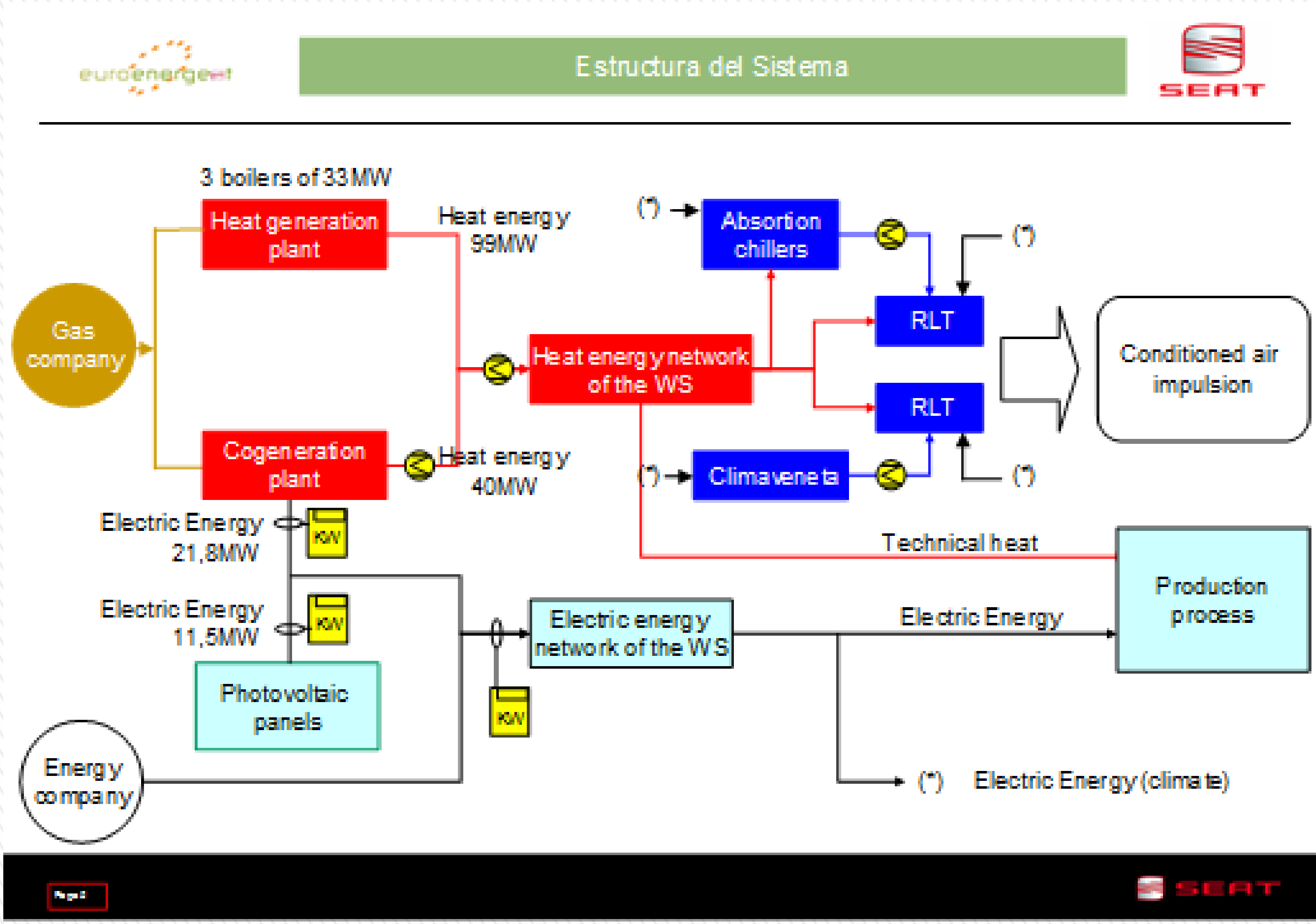


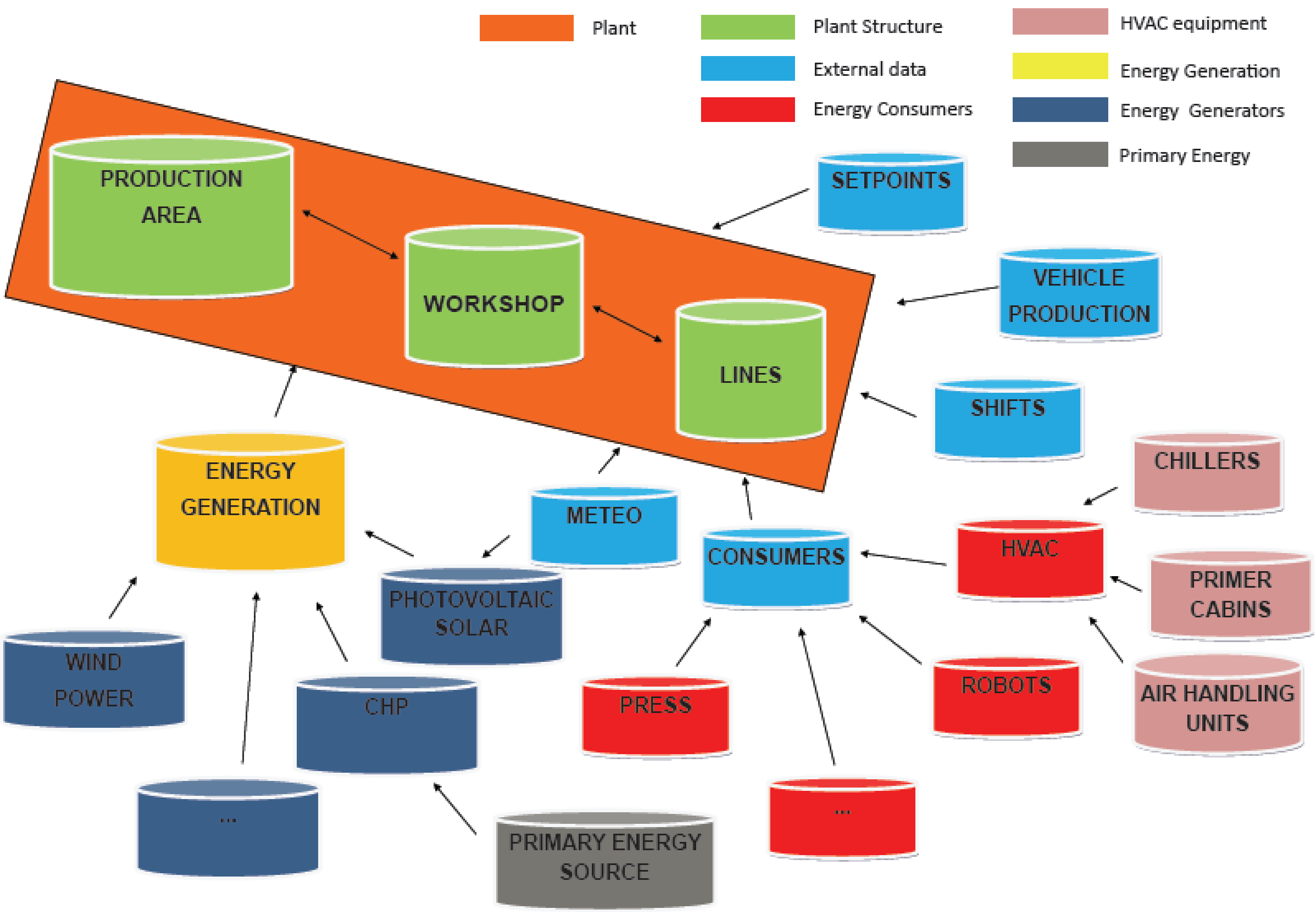
PROJECT IMPACT

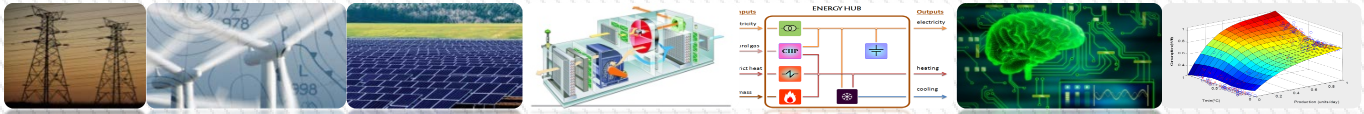
- On users.
  - Energy and GHG savings (up to 15%), real and verifiable energy and CO_2 saving information
- On social impact & policy
  - Car Industry employment and facilities within UE, new financial models (ESCO)
- On industry.
  - Car Industry competitiveness, ESCO model for EE&Renewables, diversification to other industries, Internationalization
- On research activity & technology
  - “Best Technology Available”, Energy optimization algorithms, CO_2 evaluation, real case validation

STRUCTURE OF THE GENERATION MODEL AT SEAT.

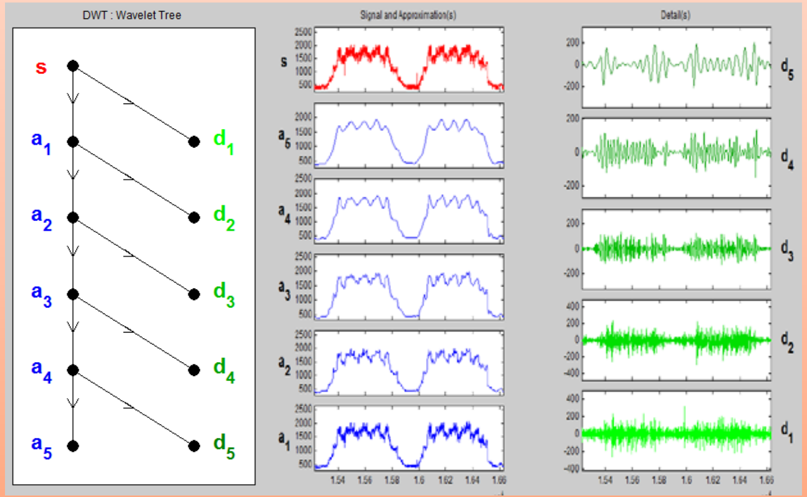



Estructura del Sistema
SEAT
3 boilers of 33MW
Heat generation plant
Heat energy 99MW
(*)
Absorption chillers
(*)
Gas company
RLT
Heat energy network of the WS
Conditioned air impulsion
RLT
Cogeneration plant
Heat energy 40MW
(*)
Climaveneta
(*)
Electric Energy 21,8MW
KW
Technical heat
Electric Energy 11,5MW
KW
Electric energy network of the WS
Electric Energy
Production process
Photovoltaic panels
KW
Energy company
(*) Electric Energy (climate)
SEAT


Plant
Plant Structure
HVAC equipment
External data
Energy Generation
Energy Consumers
Energy Generators
Primary Energy
PRODUCTION AREA
WORKSHOP
LINES
SETPOINTS
VEHICLE PRODUCTION
SHIFTS
CHILLERS
ENERGY GENERATION
METEO
CONSUMERS
HVAC
PRIMER CABINS
PHOTOVOLTAIC SOLAR
WIND POWER
CHP
PRESS
ROBOTS
AIR HANDLING UNITS
...
PRIMARY ENERGY SOURCE
...



$$W(a,b) = \frac{1}{\sqrt{a}}\int_{-\infty}^{+\infty} f(x)\phi\left(\frac{x-b}{a}\right)dx$$



Start

Step 1: **Scaling and reorganization** for each data

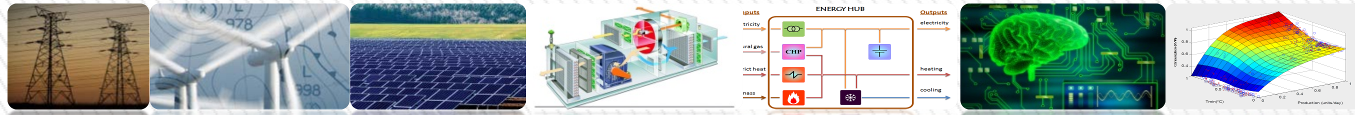
Step 2: **Wavelet Transform** Descomposition - reconstruction

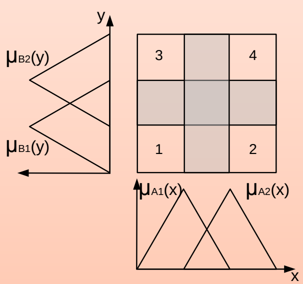
Step 3: **Training Data Set**

Step 4: **E-ANFIS training** using ETA

Step 5: **E-ANFIS evaluation:** forecast output

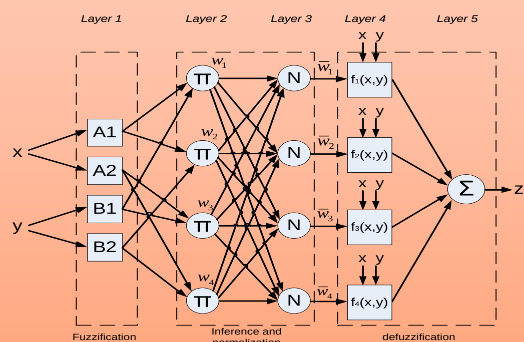
Exit

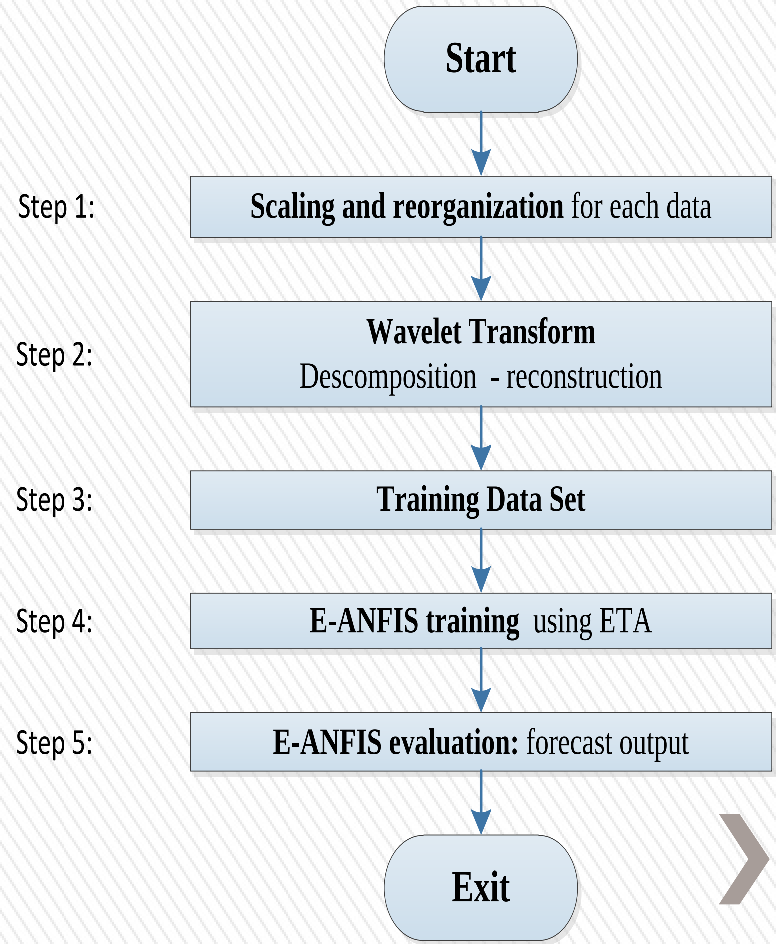


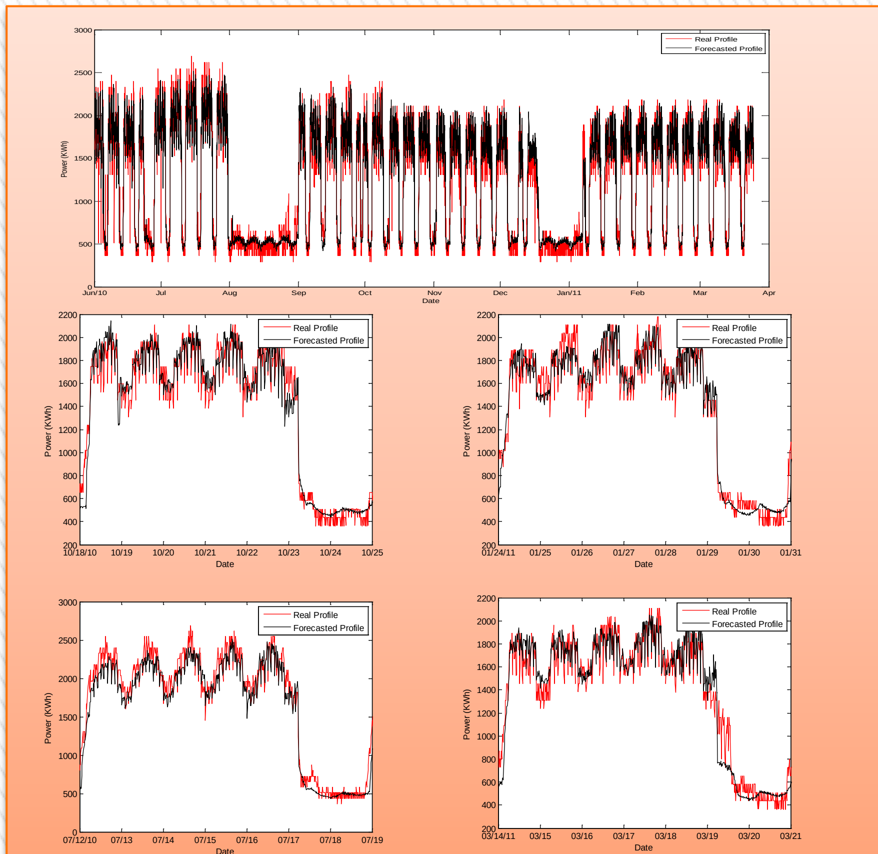


$$if\ x \in A_1 \wedge y \in B_1 \Rightarrow f_1(x,y) = p_1 e^{\alpha_1 x} + q_1 e^{\beta_1 y} + r_1$$
$$if\ x \in A_2 \wedge y \in B_2 \Rightarrow f_2(x,y) = p_2 e^{\alpha_2 x} + q_2 e^{\beta_2 y} + r_2$$
$$if\ x \in A_3 \wedge y \in B_3 \Rightarrow f_3(x,y) = p_3 e^{\alpha_3 x} + q_3 e^{\beta_3 y} + r_3$$
$$if\ x \in A_4 \wedge y \in B_4 \Rightarrow f_4(x,y) = p_4 e^{\alpha_4 x} + q_4 e^{\beta_4 y} + r_4$$

$$\omega_j = \mu_A(x) \cdot \mu_B(x)$$
$$\overline{\omega}_j = \frac{\omega_j}{\sum_{i=1}^{N} \omega_1}$$
$$Z_{\text{final}} = \sum_{j=1}^{n} \overline{\omega}_j \cdot z_j(x,y)$$







Start

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Exit

Energy Hub definition and structure

Generator Expected Models:

- Co-generation
- Thermal Boilers
- Absorption Machines
- Cooling Machines (Climaveneta)

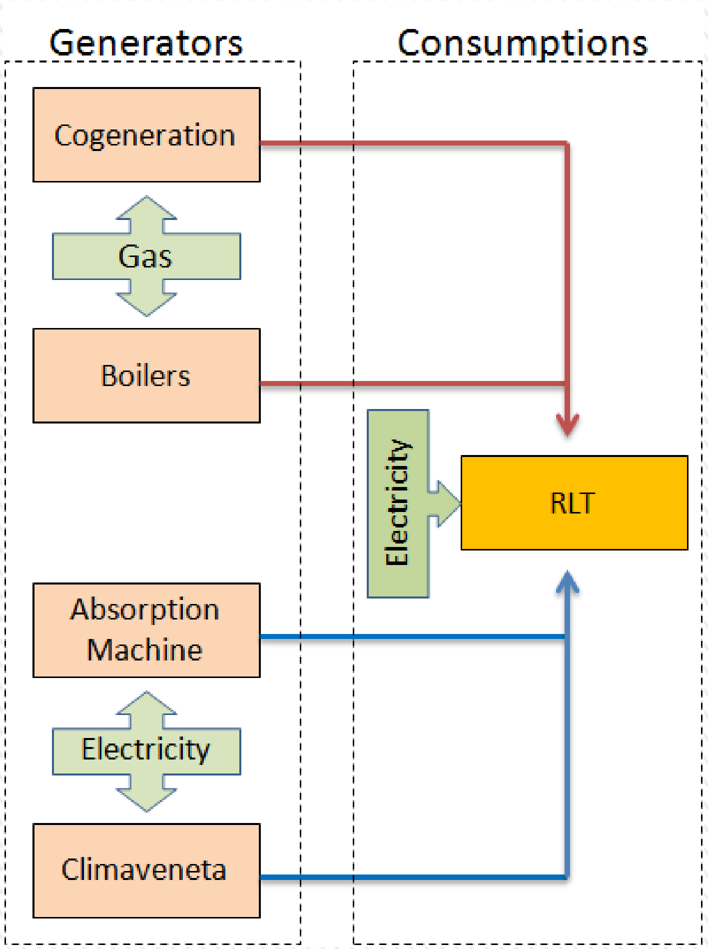
$$\boldsymbol{COG\ (\mathcal{E}, Q = f\ (Gas\ ))}$$

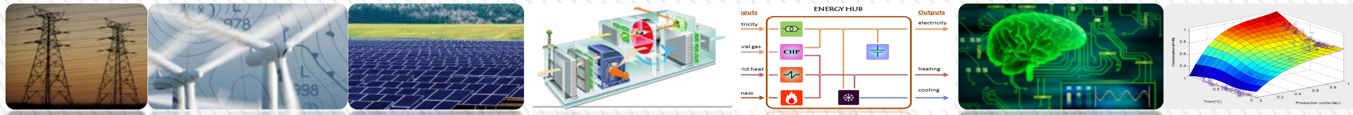
$$BOILERS\ (Q = f\,(Gas))$$

$$Abs\ Mach + \text{Climavenet}\ (Q_{cold} = f\ (\mathcal{E}))$$

Consumptions:

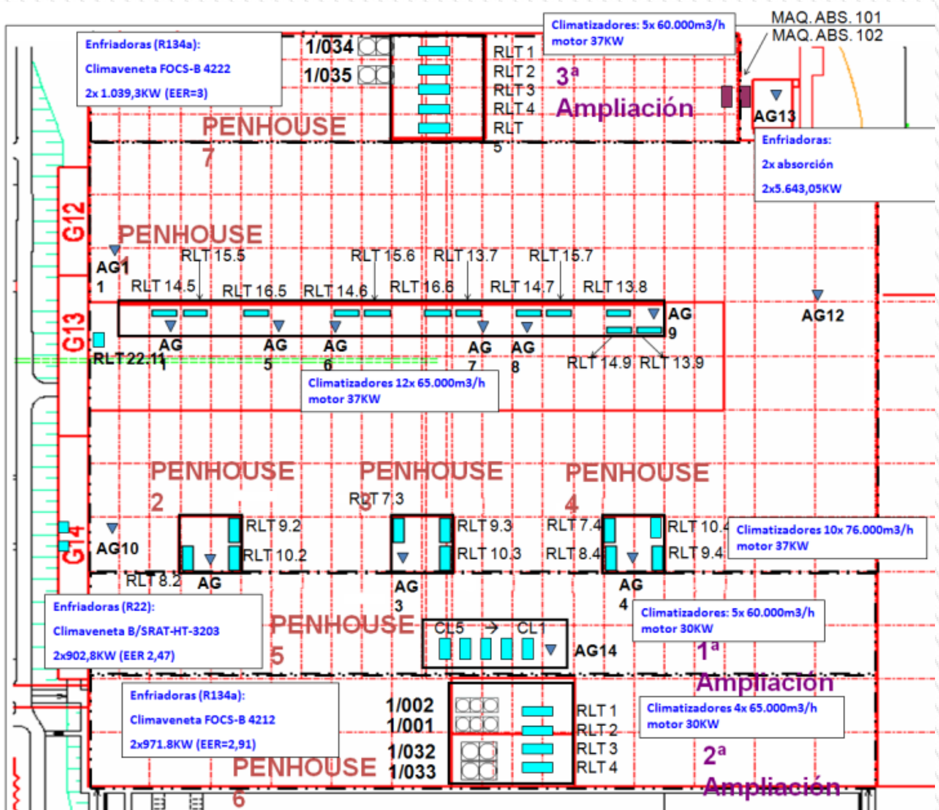
- Thermal Energy Demand (Cool/Heat)
- Electrical Energy Demand

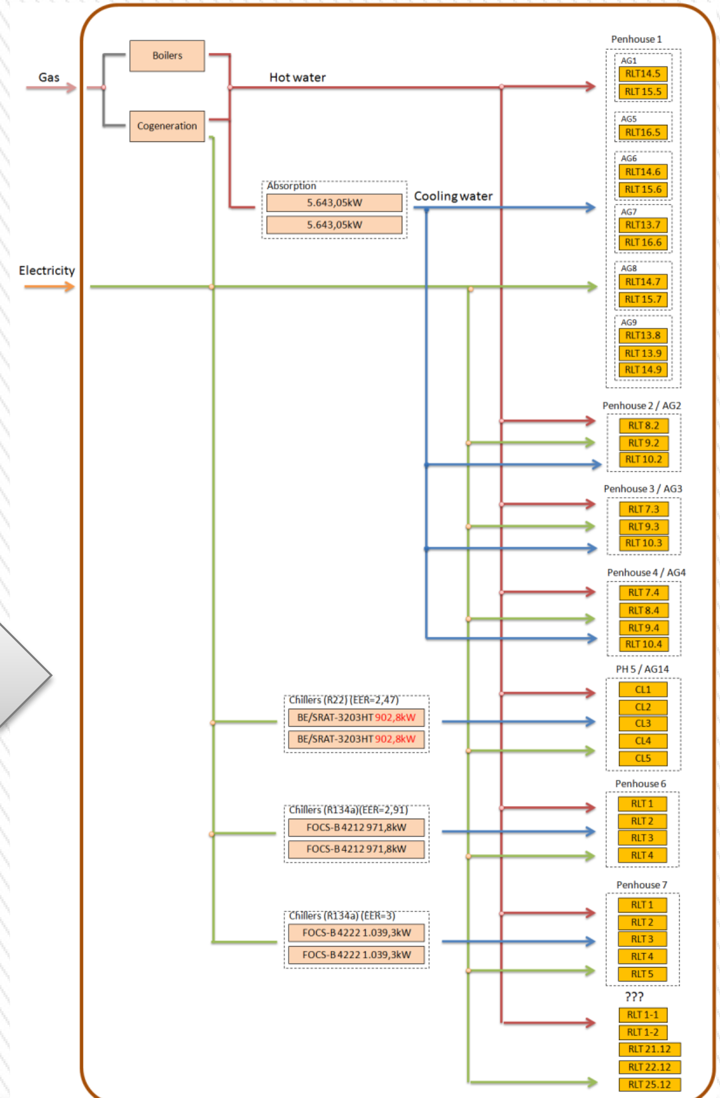


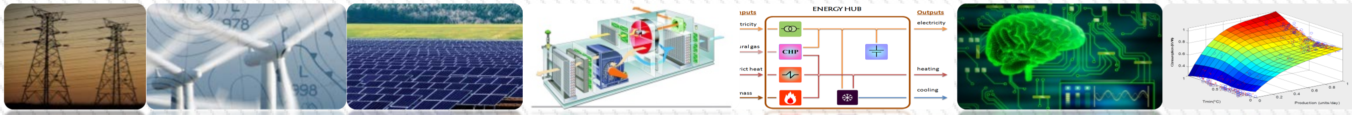


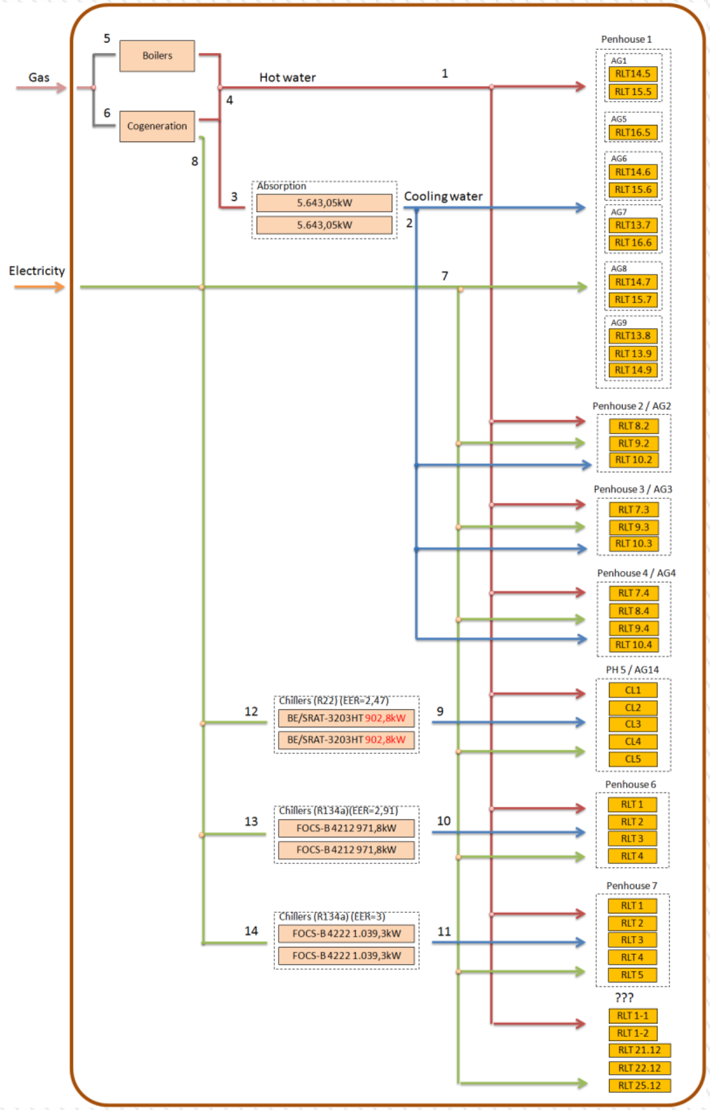
Energy Hub definition and structure

- Analysis of the pilot plant – Workshop 1









Mathematical formulation:

$P1 = Thermal\ Demand\ T1$

$P2 = Cooling\ Demand\ PH1, PH2, PH3, PH4$

$P3 = P2 * \eta_{Abs1}^{cool}$

$P4 = P2 + P3$

$P5 = f1 * P4 * \eta_{boiler}$

$P6 = (1 - f1) * P4 * \eta_{cog}^{th}$

$P7 = Electric\ Demand\ RLTs$

$P8 = \frac{P6}{\eta_{cog}^{el}}$

$P9 = Cool\ Demand\ PH5$

$P10 = Cool\ Demand\ PH6$

$P11 = Cool\ Demand\ PH7$

$P12 = P9 * \eta_{chill1}^{cool}$

$P13 = P10 * \eta_{chill2}^{cool}$

$P14 = P11 * \eta_{chill3}^{cool}$

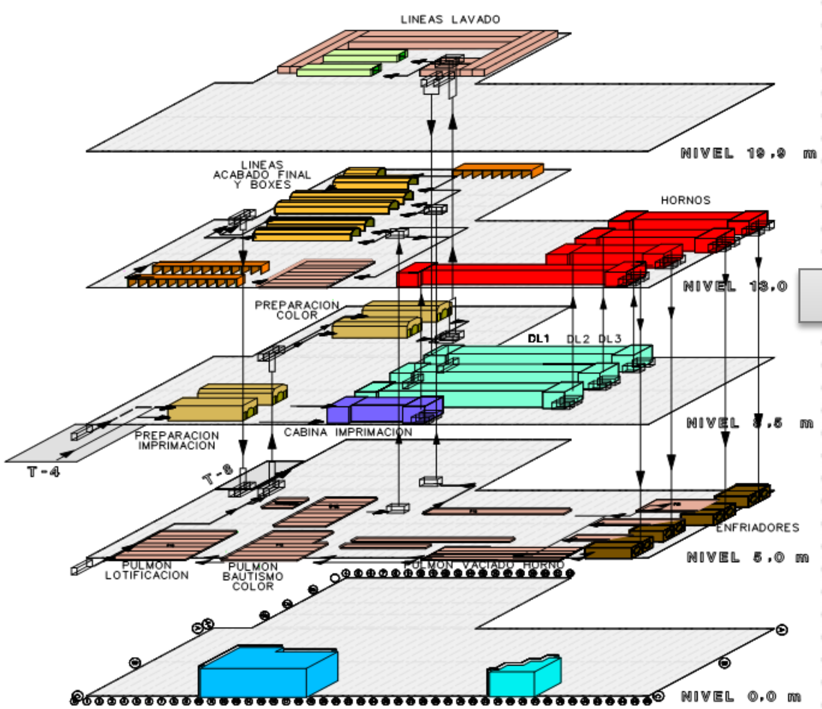
Energy Requirements:

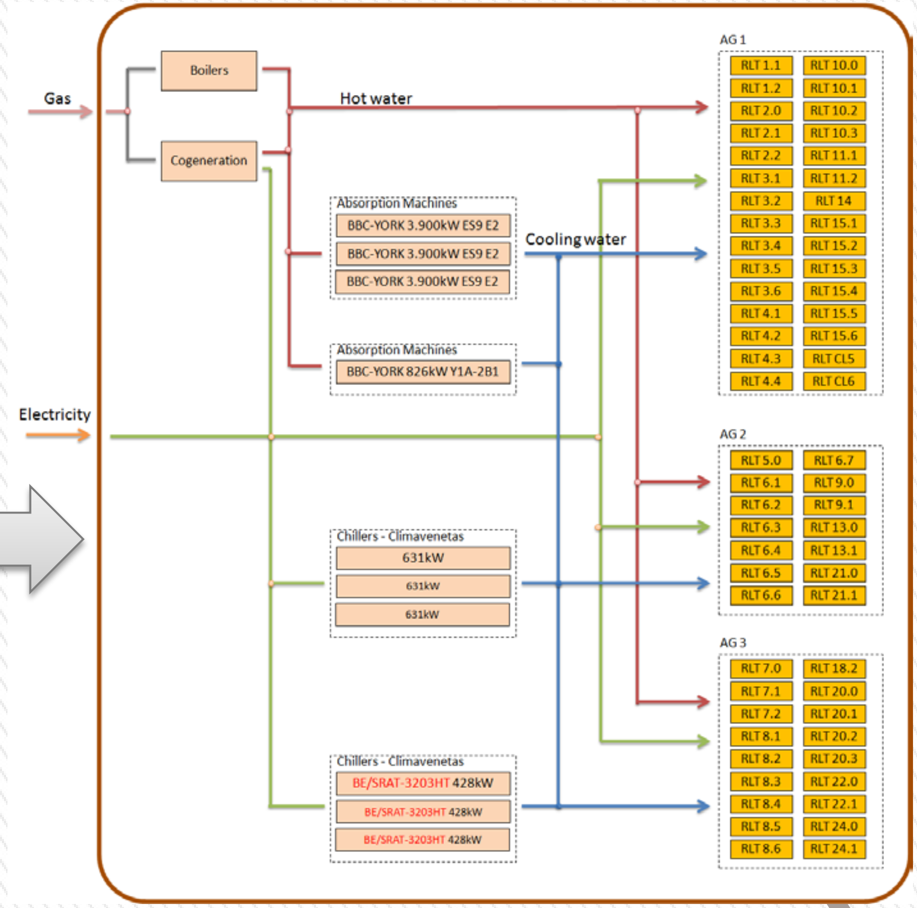
$Gas\ Demand = P5 + P6$

$Electic\ Demand\ Grid = P12 + P13 + P14 - P8$

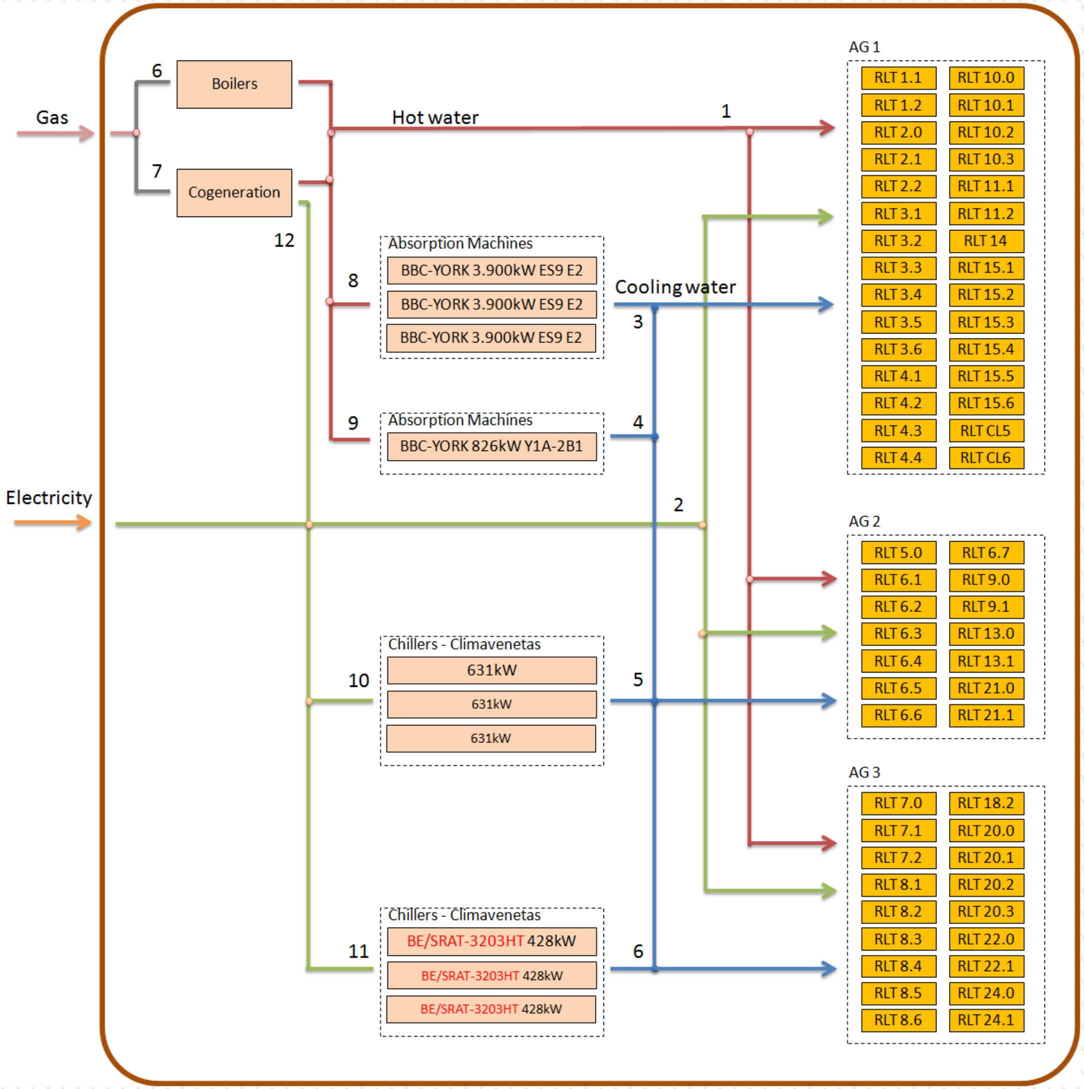
Energy Hub definition and structure

- Analysis of the pilot plant – Workshop 5
  - Air condiotining for comfort
  - Painting lines





Energy Hub definition and structure



Mathematical formulation:

$$P1 = Thermal\ Demand$$

$$P2 = Electric\ Demand$$

$$P3 + P4 + P5 + P6 = Cooling\ Demand$$

$$P7 = f1 * \eta_{boiler} * (P1 + P9 + P10)$$

$$P8 = (1 - f1) * \eta_{boiler} * (P1 + P9 + P10)$$

$$P9 = f2 * \eta_{Abs1}^{cool} * (P3 + P4 + P5 + P6)$$

$$P10 = f3 * \eta_{Abs2}^{cool} * (P3 + P4 + P5 + P6)$$

$$P11 = f4 * \eta_{chill1}^{cool} * (P3 + P4 + P5 + P6)$$

$$P12 = f4 * \eta_{chill1}^{cool} * (P3 + P4 + P5 + P6)$$

$$P13 = \frac{P8}{\eta_{cog}^{el}}$$

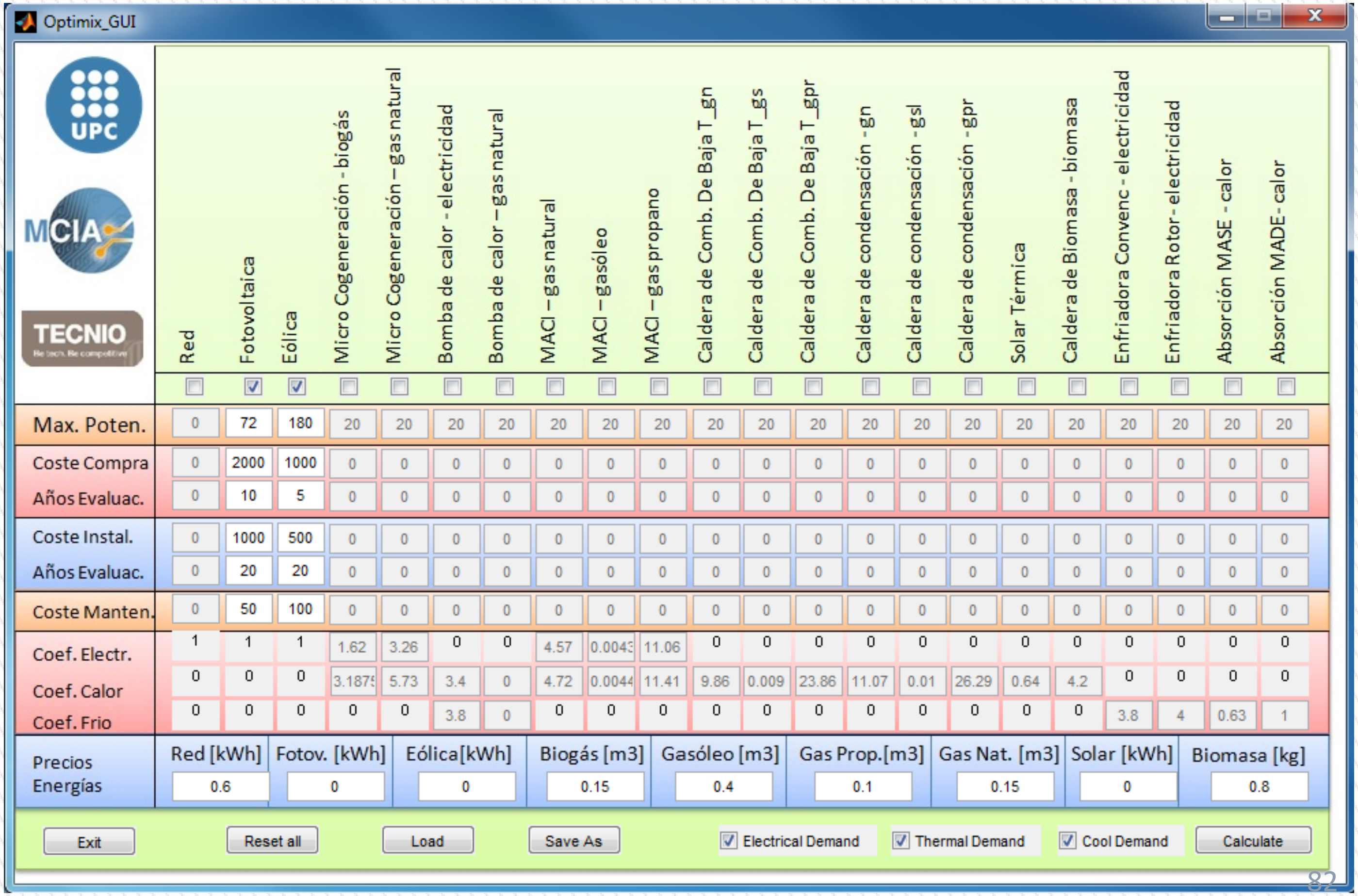
Energy Requirements:

$$Electic\ Demand\ Grid = P2 + P11 + P12 - P13$$

$$Gas\ Demand = P7 + P8$$

System optimization for energy management.

- Test of optimization algorithms – Graphic user interface of scenario´s configuration:



➢ Optimization criteria:

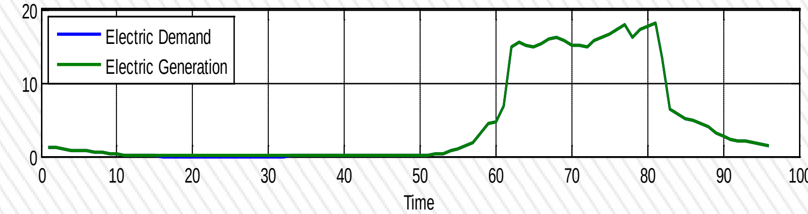
$$C_{total} = C_{grid} + C_{gas} + C_{pv}$$

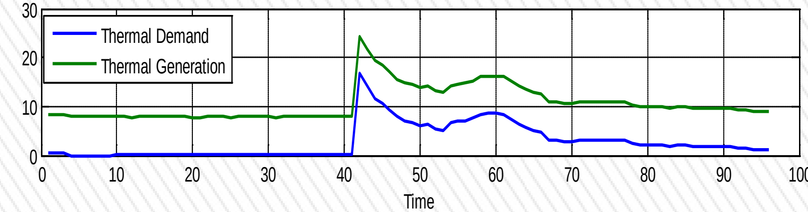
$$\min imize: \quad C_{total}$$

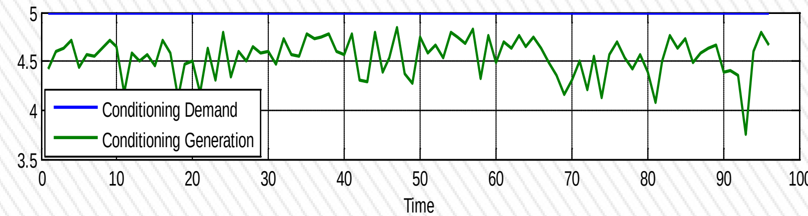
$$subject\,to: \quad P_{total}^{out} = CP_{total}^{in}$$

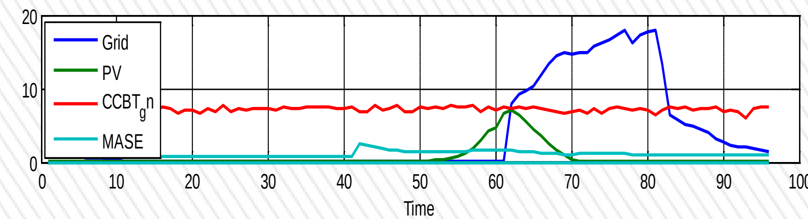
$$\overline{P}_{\min}^{in} \le \overline{P}^{in} \le \overline{P}_{\max}^{in}$$

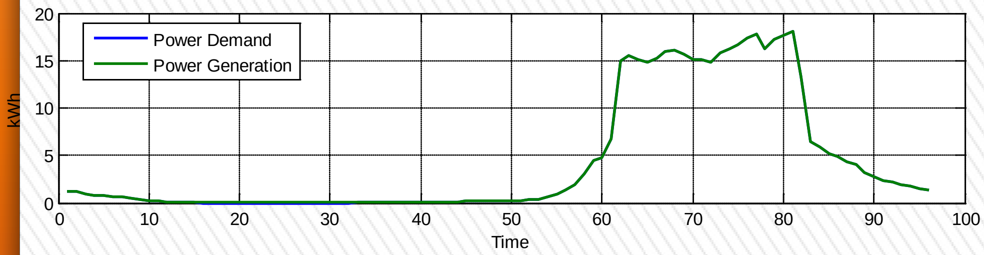
- Test of optimization algorithms

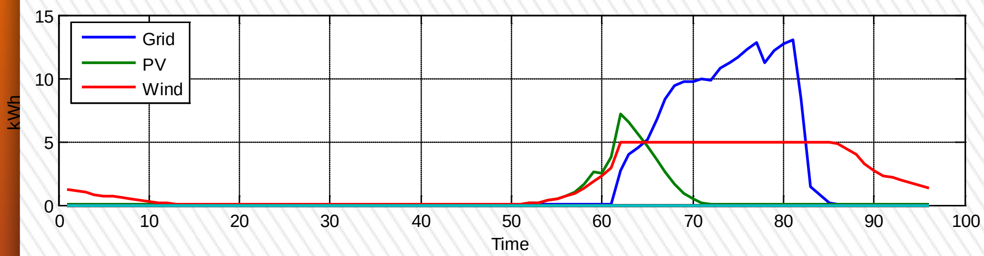


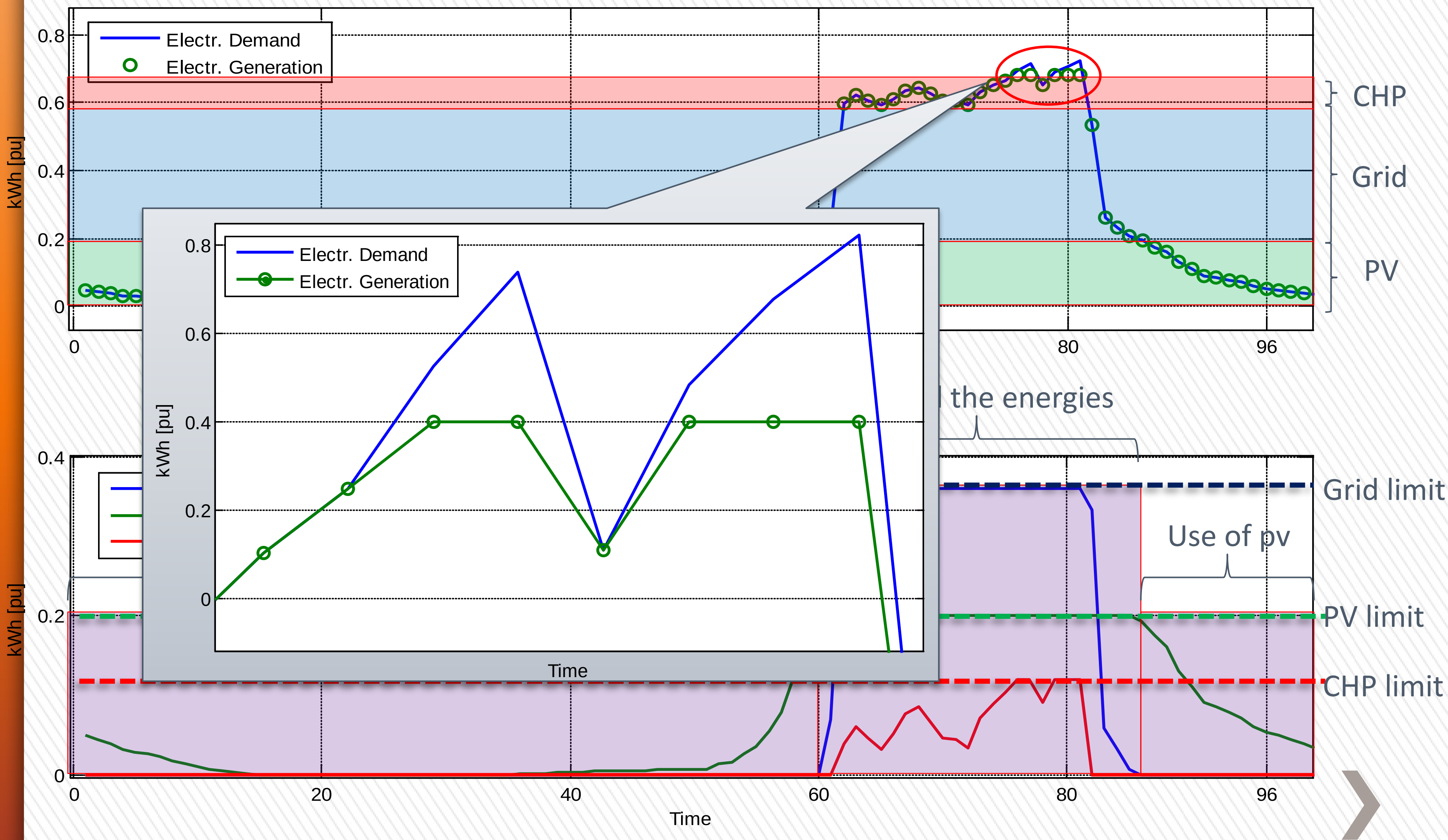


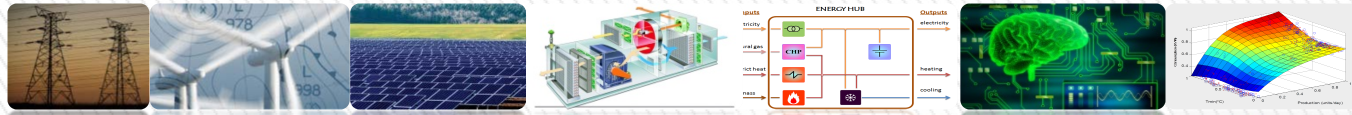




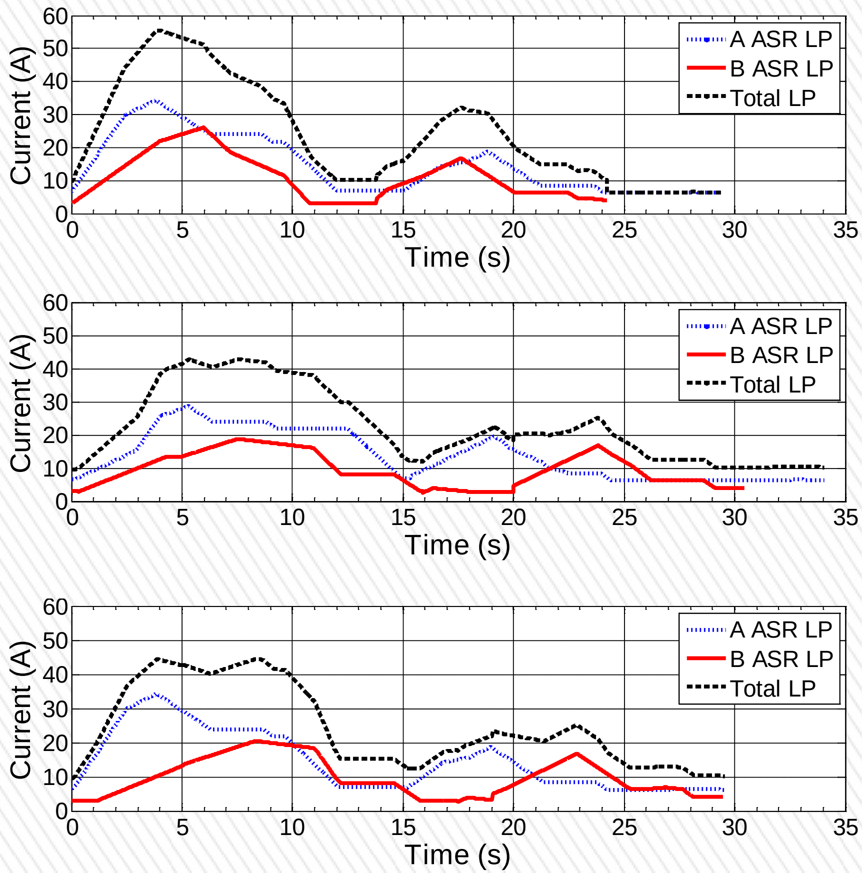


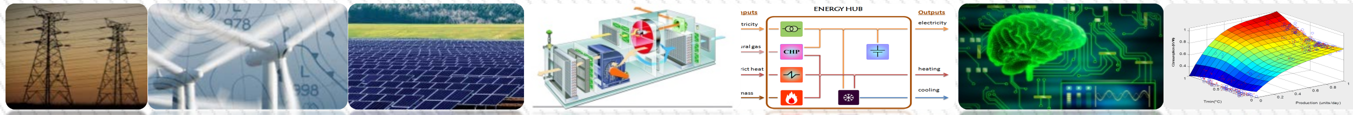



Electr. Demand
Electr. Generation
CHP
Grid
PV
kWh [pu]
0.8
0.6
0.4
0.2
0
0
80
96
Time
the energies
Grid limit
Use of pv
PV limit
CHP limit
20
40
60



Initial (at the top) LPs, GA (at the middle)and MOGA (at the bottom) LP results.





Summary results for the Implemented GA and MOGA

Description	GA	MOGA	Unit	Observation
ASR number	2		unit	A and B
Motors for control	4		unit	x and y axis
Total searched delays	8		unit	4 by ASR
Allowed maximum delay	5		s	
Maximum obtenaided delay	4.9	0.1	s	
Initial total time	29.4	29.4	s	
End total time	34	29.5	s	With MOGA the total delay is less
Initial maximum total load peak	56	56	A	
End maximum total load peak	44	44,49	A	
Load peak reduction	21%	21%	%	
Average CPU time	5	90	s	Intel® Core™2 Quad CPU Q6600 @ 2.400 GHz