The validation of SADDE methodology in the electricity market

IIIA-CSIC

Jordi Sabater

Pere Garcia

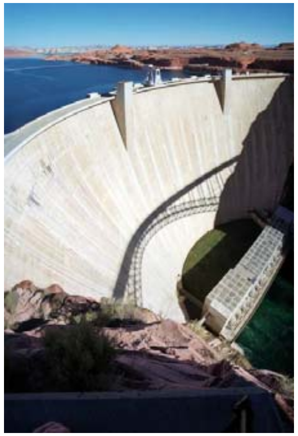
Jaume Agusti

Carles Sierra

David de la Cruz

The power market

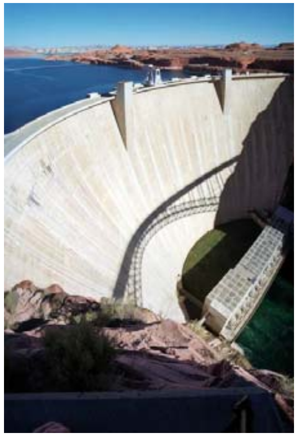
Producers



Network

Consumers

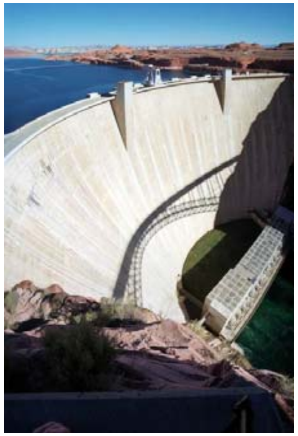
Producers



They use different mechanisms to generate electrivity:

•Hidroelectric power stations

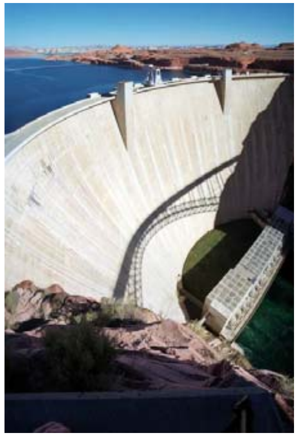
Producers



They use different mechanisms to generate electrivity:

- •Hidroelectric power stations
- •Nuclear power stations

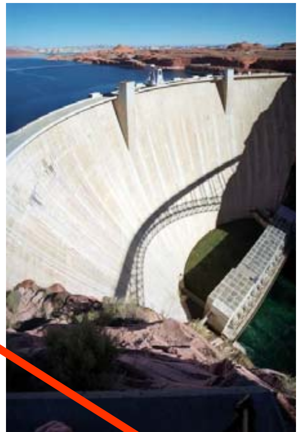
Producers

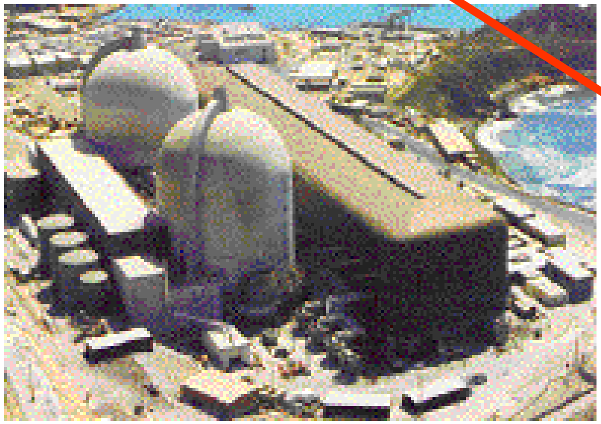


They use different mechanisms to generate electrivity:

- •Hidroelectric power stations
- •Nuclear power stations
- •Coal-fired, gas-fired and fuel-fired power stations

Producers

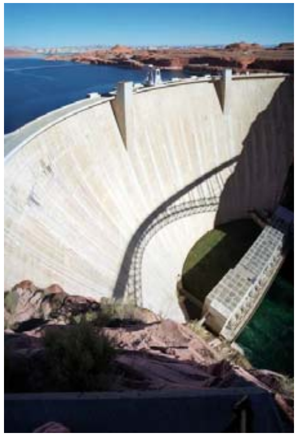




They use different mechanisms to generate electrivity:

- •Hidroelectric power stations
- •Nuclear power stations
- •Coal-fired, gas-fired and fuel-fired power stations
- •Alternative power stations (like the eolic)

Producers

They use different mechanisms to generate electricity:

- •Hidroelectric power stations
- •Nuclear power stations
- •Coal-fired, gas-fired and fuel-fired power stations
- •Alternative power stations (like the eolic)

Each type of power station has its own production features.

For instance: hidroelectric is cheap and come on stream very quickly but it is limited.

Consumers

Large industrial processes and local power distribution utilities.

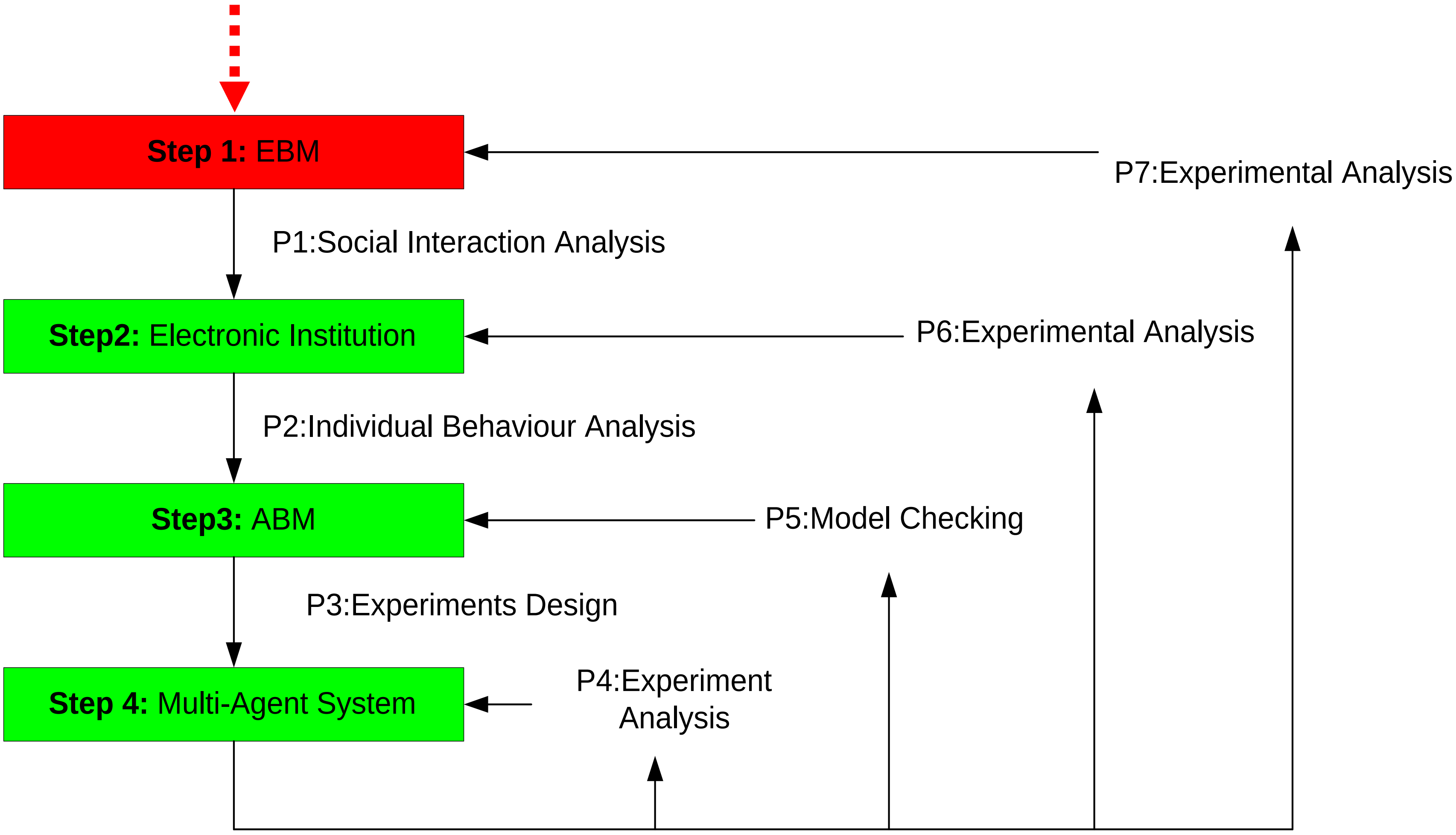
Network

The free power market between producers and consumers is mediated by an independent system operator.

The goal of the system operator is to match offer and demand while maintaining the network safe.

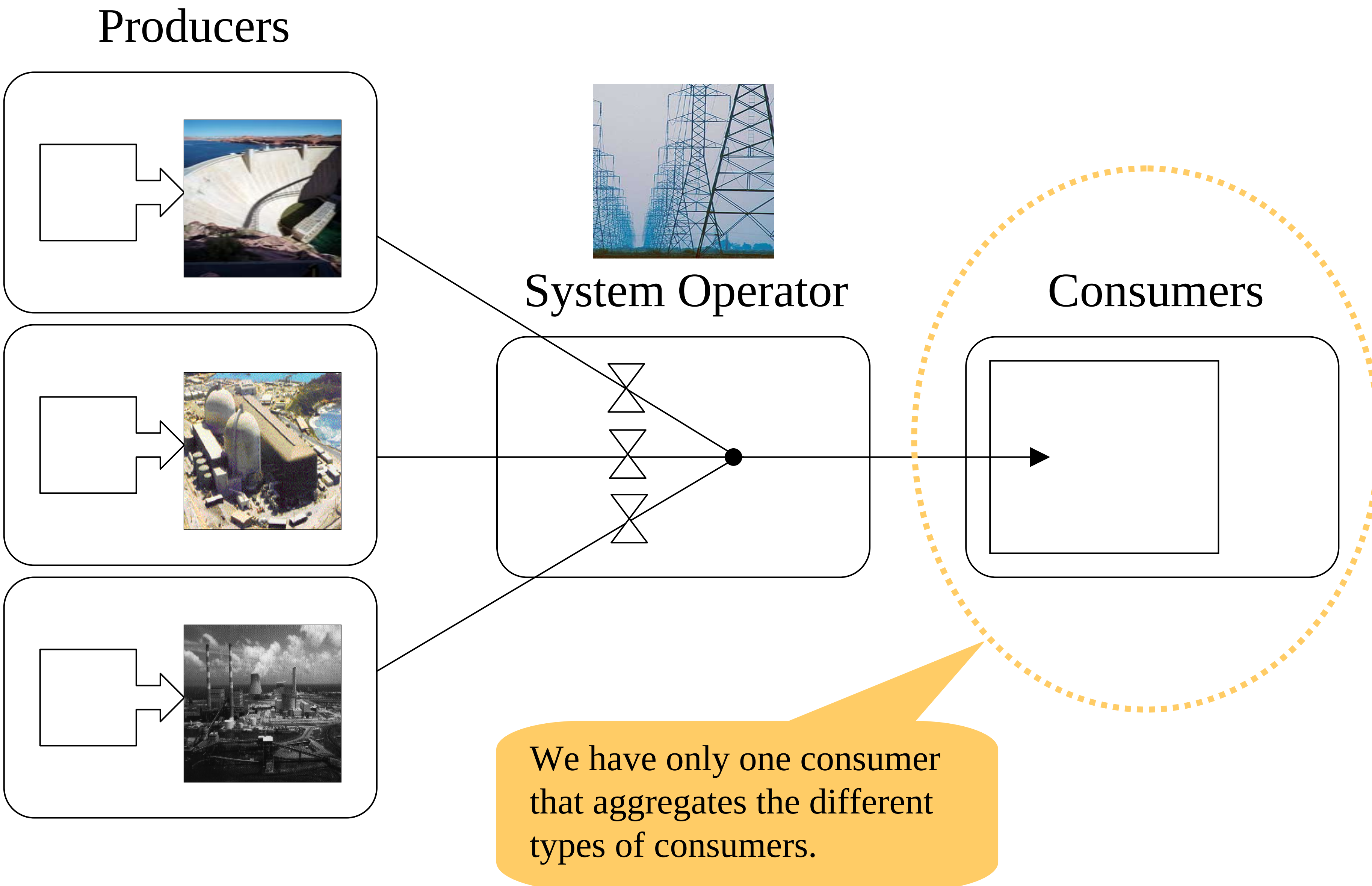
Applying the SADDE methodology

The power market: EBM



Assumptions

Step1: EBM



Assumptions

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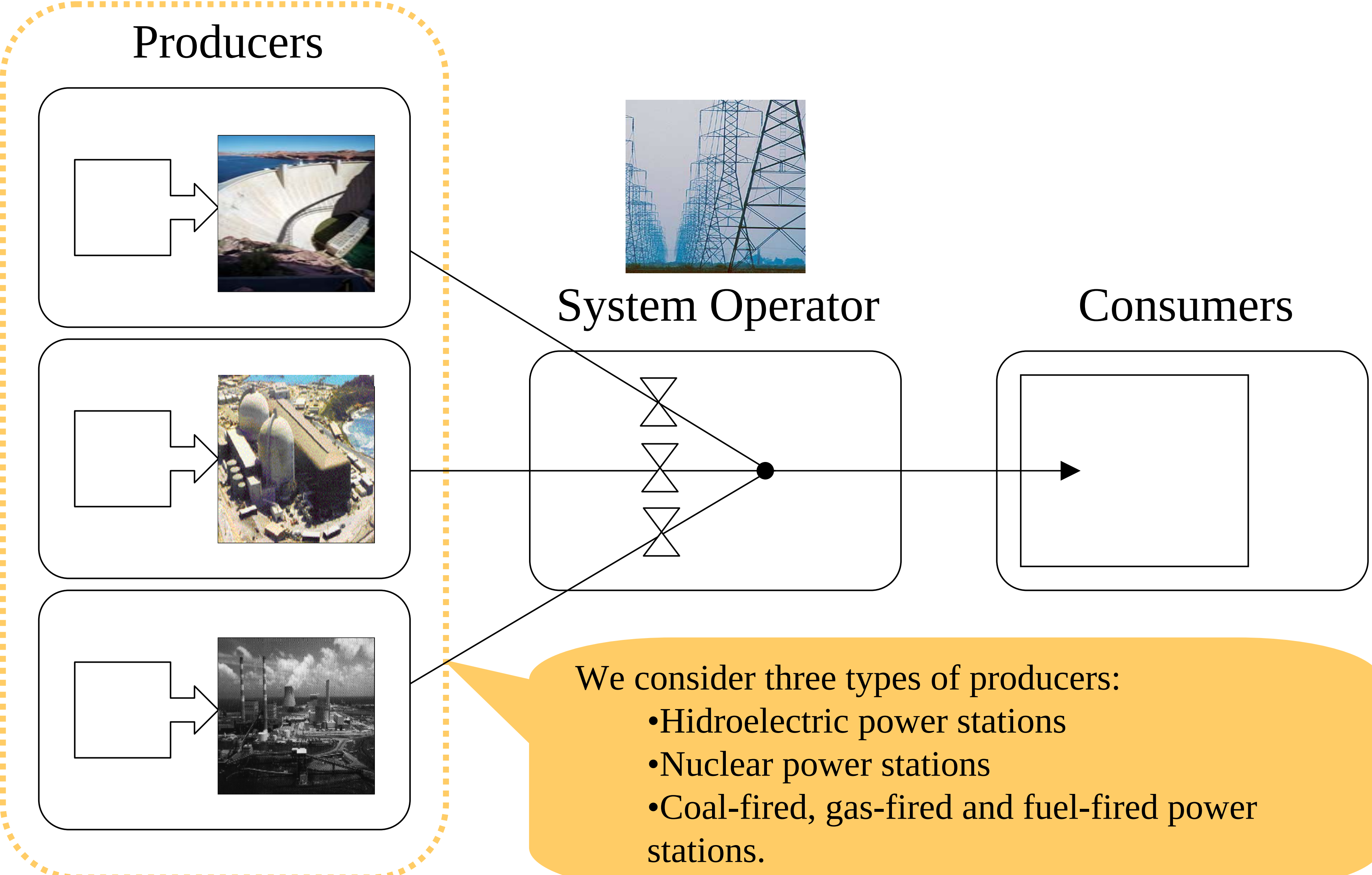
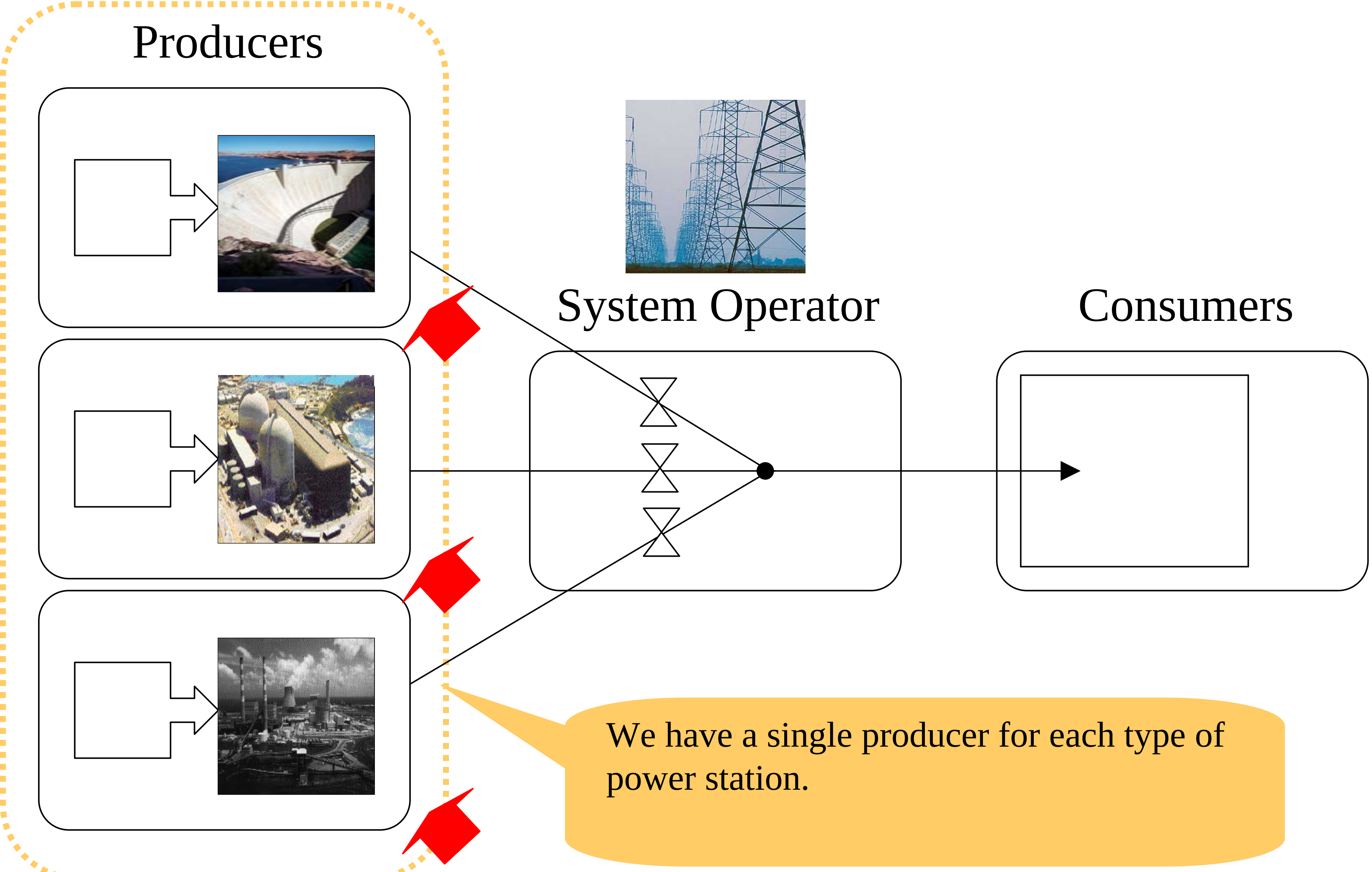


We consider three types of producers:

- Hidroelectric power stations
- Nuclear power stations
- Coal-fired, gas-fired and fuel-fired power stations.

Assumptions



Assumptions

• We assume a complete topology for the power network.

ie: all producers can supply power to all consumers.

• The system operator does not take into account the type of producer to assign power demand.

• The system operator never forces producers to generate more power to cover a possible deficit.

The EBM is tailored to never have a power deficit greater than the 10% of produced power. This 10% is the extra production capacity that power stations are obliged to produce in real life to cover eventual shortages.

Producers in the EBM

There are three parameters that typify a power station:

MaxN: Maximum production capacity (in MW).
MaxI: Maximum power increase per hour (in MW).
MaxD: Maximum power decrease per hour (in MW).

Type	MaxN	MaxI	MaxD
Hidroelectric 	9000	5000	-5000
Nuclear 	14000	3000	-2000
C,F,G-fired 	18000	6000	-4000

Producers in the EBM

Producers have a mechanism to decide the production for the next hour (*t+1*).

This mechanism takes into account:

- The demand at `t-2`, `t-1` and `t`.
- The efficiency of the power station respect to the global efficiency of the system.
- The surplus and deficit of power in the system at time `t-1`.
- The time of the day.
- And finally, the restrictions due to the type of power station.

Producers in the EBM

- The changes of power demand between time $t-2$, $t-1$ and t using the following function:

$$X = \begin{cases} var2 + var4 & \text{IF } var3 > 0 \text{ AND } var2 > 0 \text{ AND } var4 > 0 \\ (var2 + var3)/2 & \text{IF } var2 \leq 0 \text{ AND } var3 > 0 \\ var3/2 & \text{IF } var2 < 0 \text{ AND } var3 \leq \text{ AND } var4 < 0 \\ var2 + var4/2 & \text{IF } var2 \leq \text{ AND } var3 < 0 \text{ AND } var4 > 0 \\ var2 & \text{OTHERWISE} \end{cases}$$

where *var2* is the increase or decrease of power consumption between $t-1$ and t, *var3* is the increase or decrease of power consumption between $t-2$ and $t-1$ and $var4 = var2 - var3$.

Producers in the EBM

- The efficiency of a power station at time t (EnergyProd(t)/MaxN) in comparison to the global efficiency of the system (TotalDemand(t)/41000) with an efficiency limit of 70%

$$Y = \begin{cases} \max\left(X, \frac{\text{MaxN} \cdot \text{TotalDemand(t)}}{41000 - \text{EnergyProd(t)}}\right) & \text{IF } \left(\frac{\text{TotalDemand(t)}}{41000} > \frac{\text{EnergyProd(t)}}{Max\_N}\right) \\ & \text{AND excess(t)} = 0 \\ X & \text{IF } \frac{\text{EnergyProd(t)}}{MaxN} < 0.7 \\ 0 & \text{IF } X > 0 \text{ AND } \frac{\text{EnergyProd(t)}}{MaxN} \geq 0.7 \\ min(X, 0.7 \cdot \text{MaxN} - \text{EnergyProd(t)}) & \text{OTHERWISE} \end{cases}$$

- Every power station produces spear energy (Reserve(t+1)) to avoid possible power shortages.

$$Z = \begin{cases} max\left(\frac{\text{Reserve(t+1)}}{3} - \frac{\text{SpearEnergy(t)}}{3}, Y - \frac{\text{SpearEnergy(t)}}{3}\right) & \text{IF SpearEnergy(t)} < 0 \\ Y + \frac{\text{Reserve(t+1)}}{3} - \text{excess(t)} & \text{OTHERWISE} \end{cases}$$

This spear energy production changes during the day following the function:

$$\text{Reserve(t)} = \begin{cases} 3000 & \text{IF } t = 22(mod 24) \\ 0 & \text{IF } t = 23(mod 24) \\ 1000 & \text{IF } t < 4(mod 24) \\ 1500 & \text{OTHERWISE} \end{cases}$$

Producers in the EBM

- The technical features of the power station.

$$\text{var(t+1)} = \begin{cases} min(Z, \text{MaxI}, \text{MaxN}) & Z > 0 \\ max(Z, \text{MaxD}, 0) & \text{OTHERWISE} \end{cases}$$

where *MaxI* is the maximum power increase per hour and *MaxD* is the maximum power decrease per hour.

Depending on the type of power station these constants have the following values:

TYPE of POWER STATION	MaxN	MaxI	MaxD
Hydraulic	9000	5000	-5000
Nuclear	14000	3000	-2000
coal-fired, gas-fired and fuel-fired	18000	6000	-4000

So, the power produced by a power station at time $t + 1$ will be:

$$\text{EnergyProd(t+1)} = \text{EnergyProd(t)} + \text{var(t+1)}$$

Producers in the EBM

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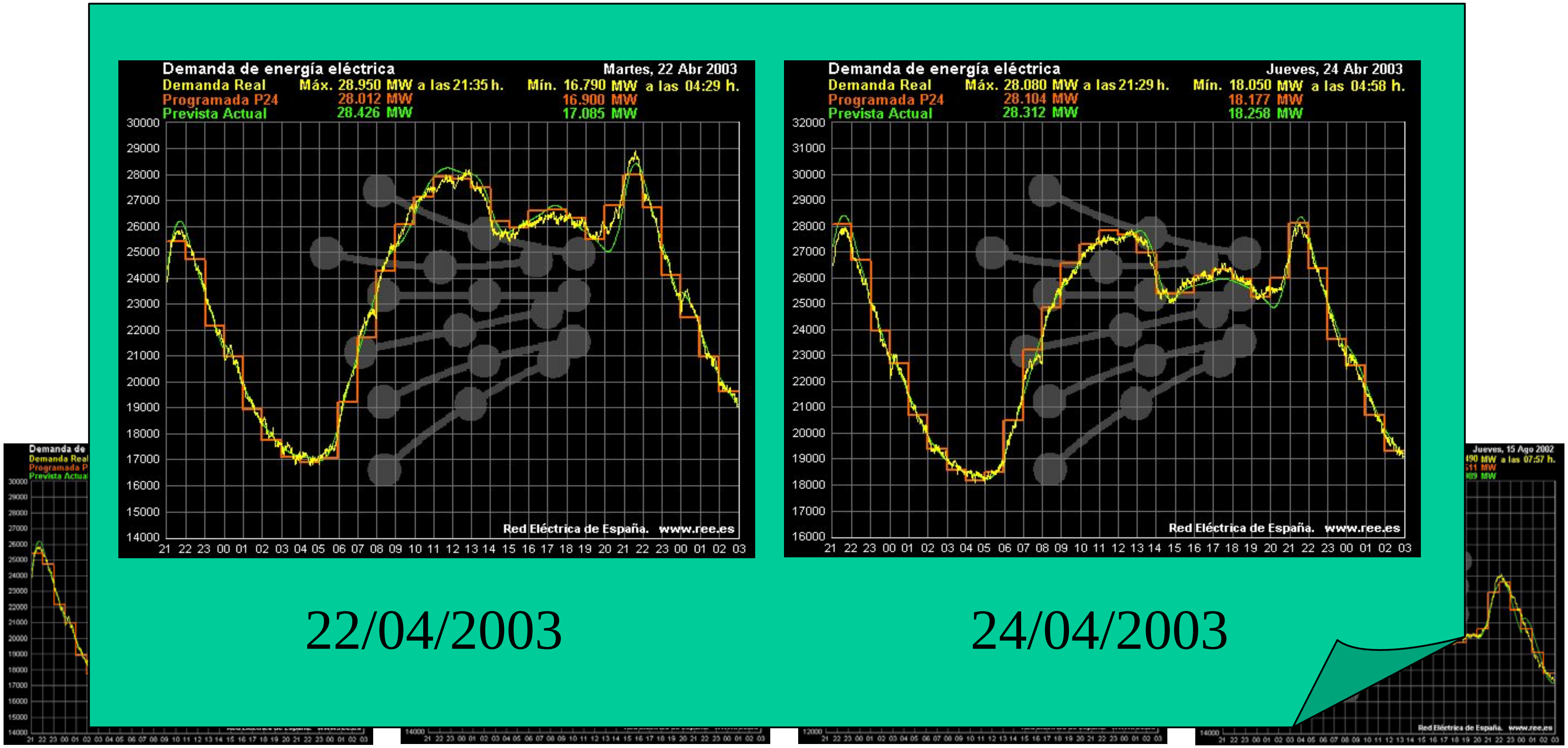
The demand in the EBM



Working day Saturday Sunday Holidays

The demand in the EBM

Using these patterns we can simulate the demand every hour.

five working days + Saturday + Sunday

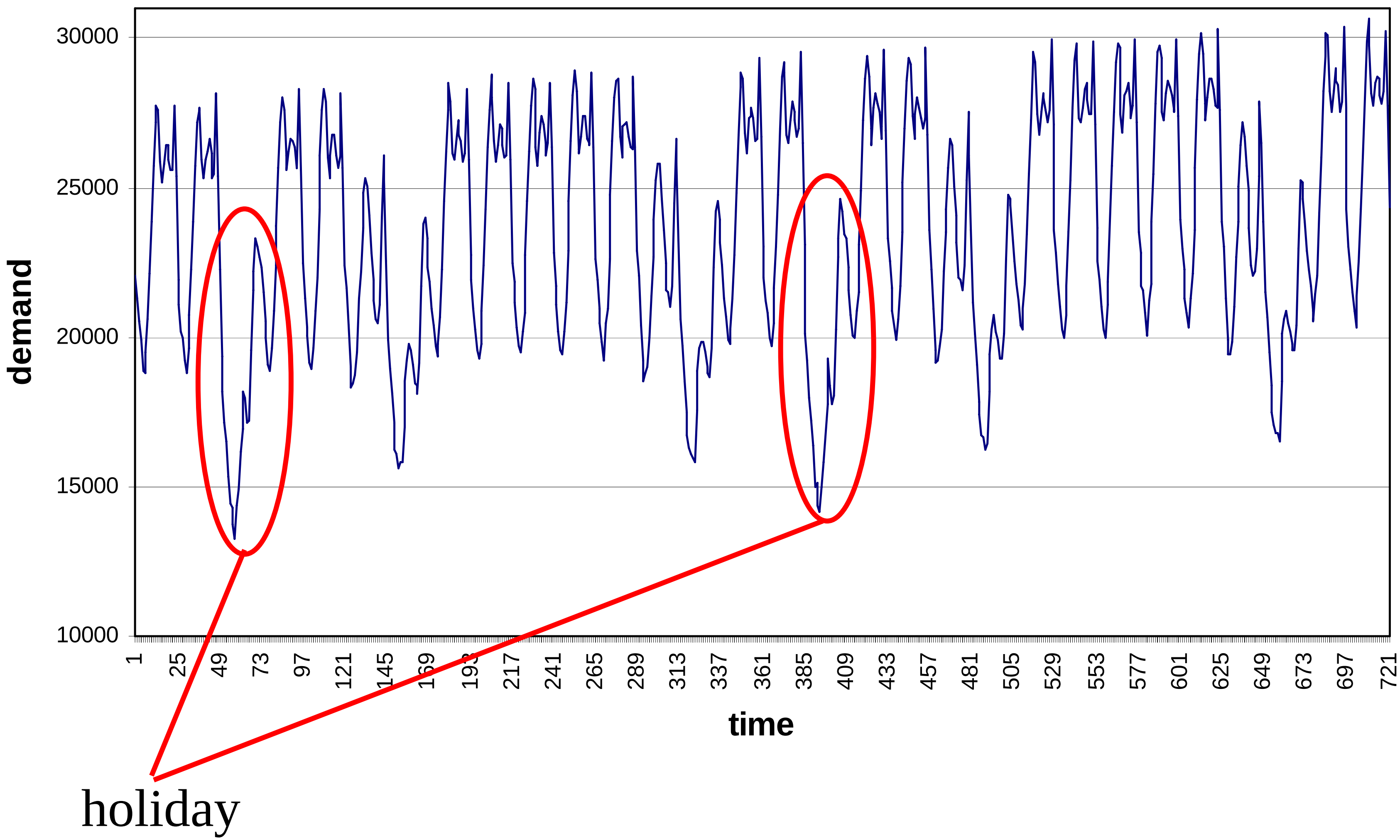
We substitute one of these days by a holiday with a probability of 1/15.

Once decided the consumption pattern for a day, we compute the demand of energy at time `t` using the formula:

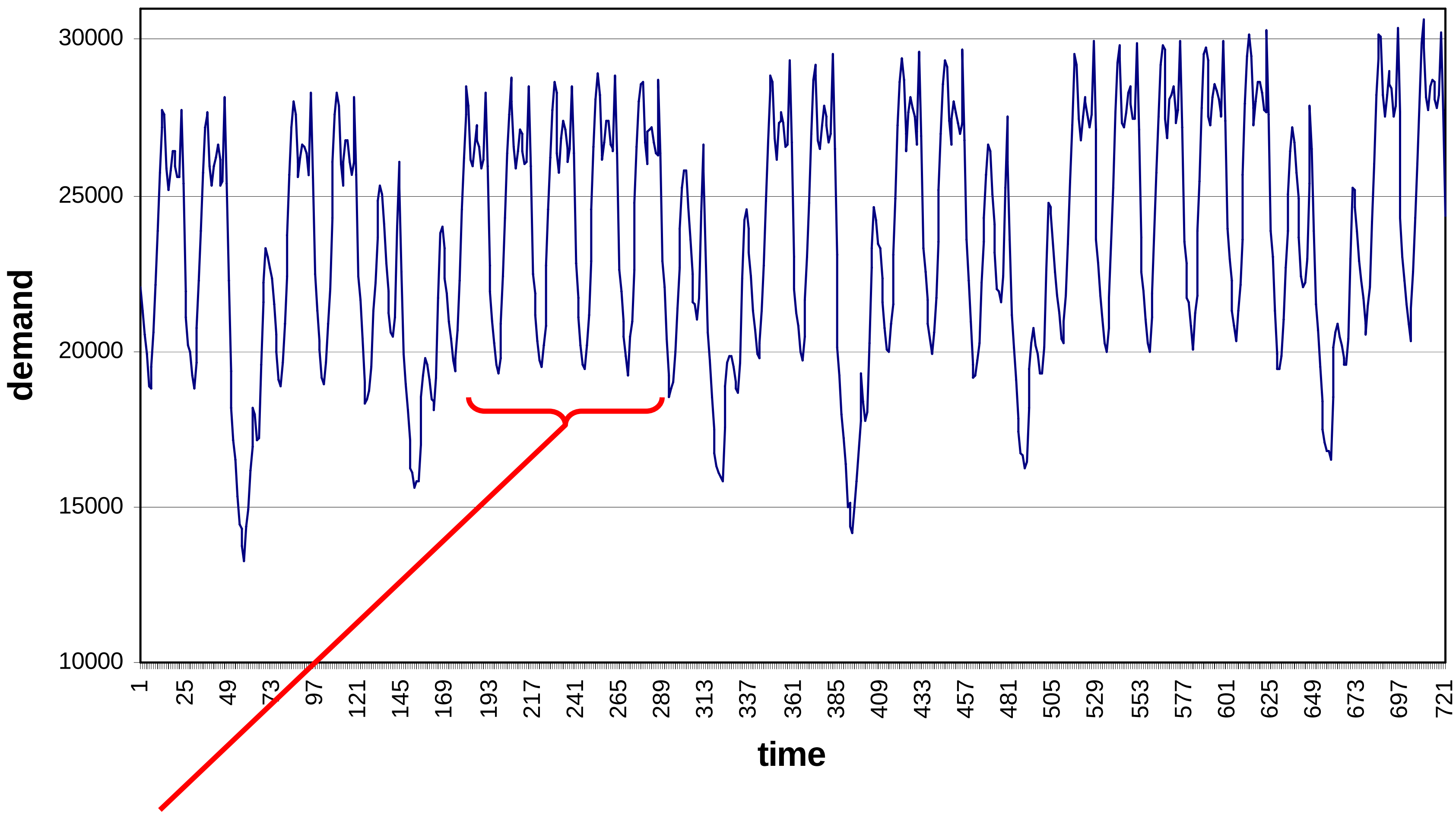
$$Demand(t) = Pattern(t) + rand(-250,250) \cdot (1 + \sin\left(\frac{\pi \cdot t}{4380}\right) \cdot 0.2)$$

The demand in the EBM

Step1: EBM

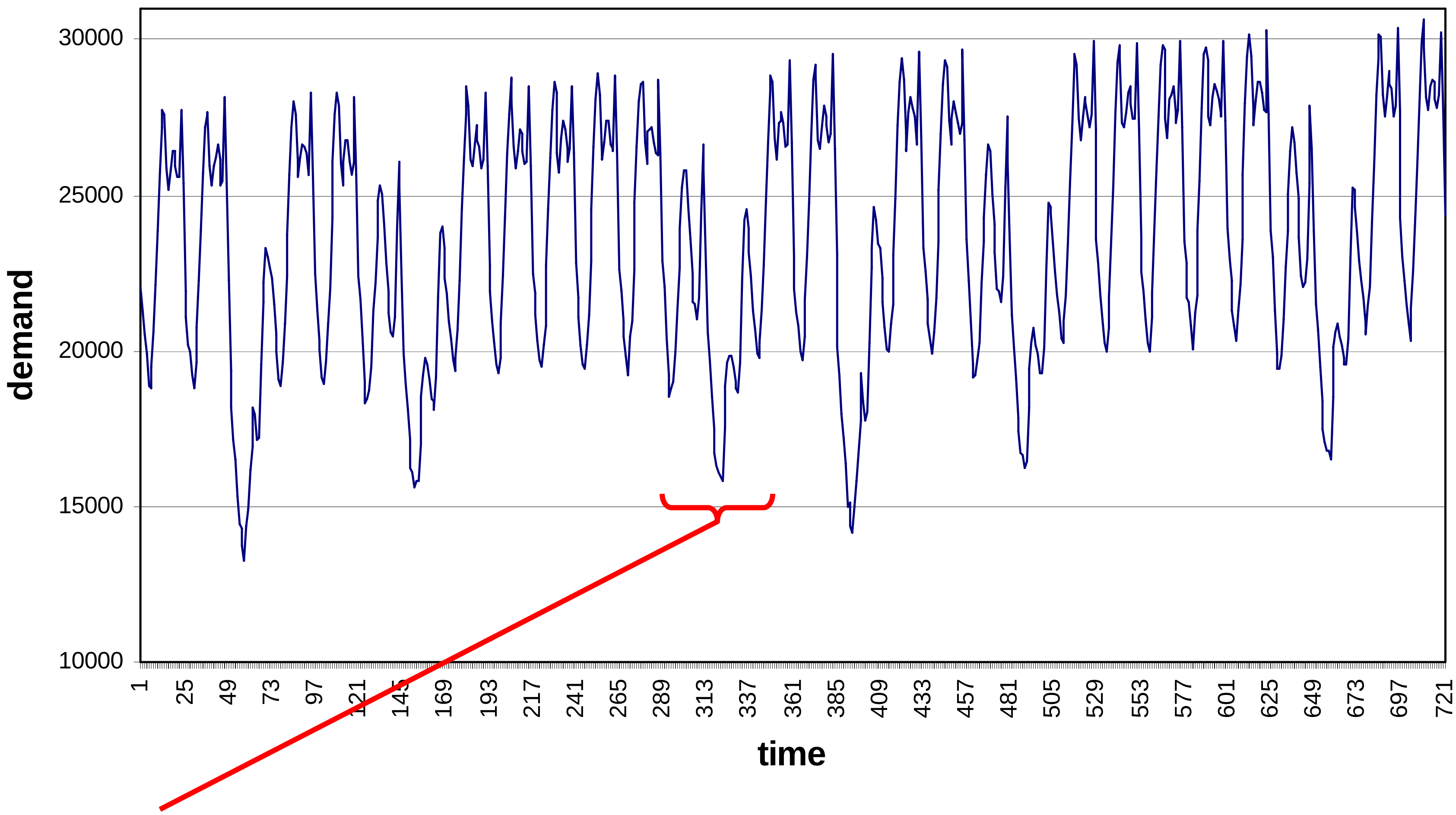


The demand in the EBM



working days

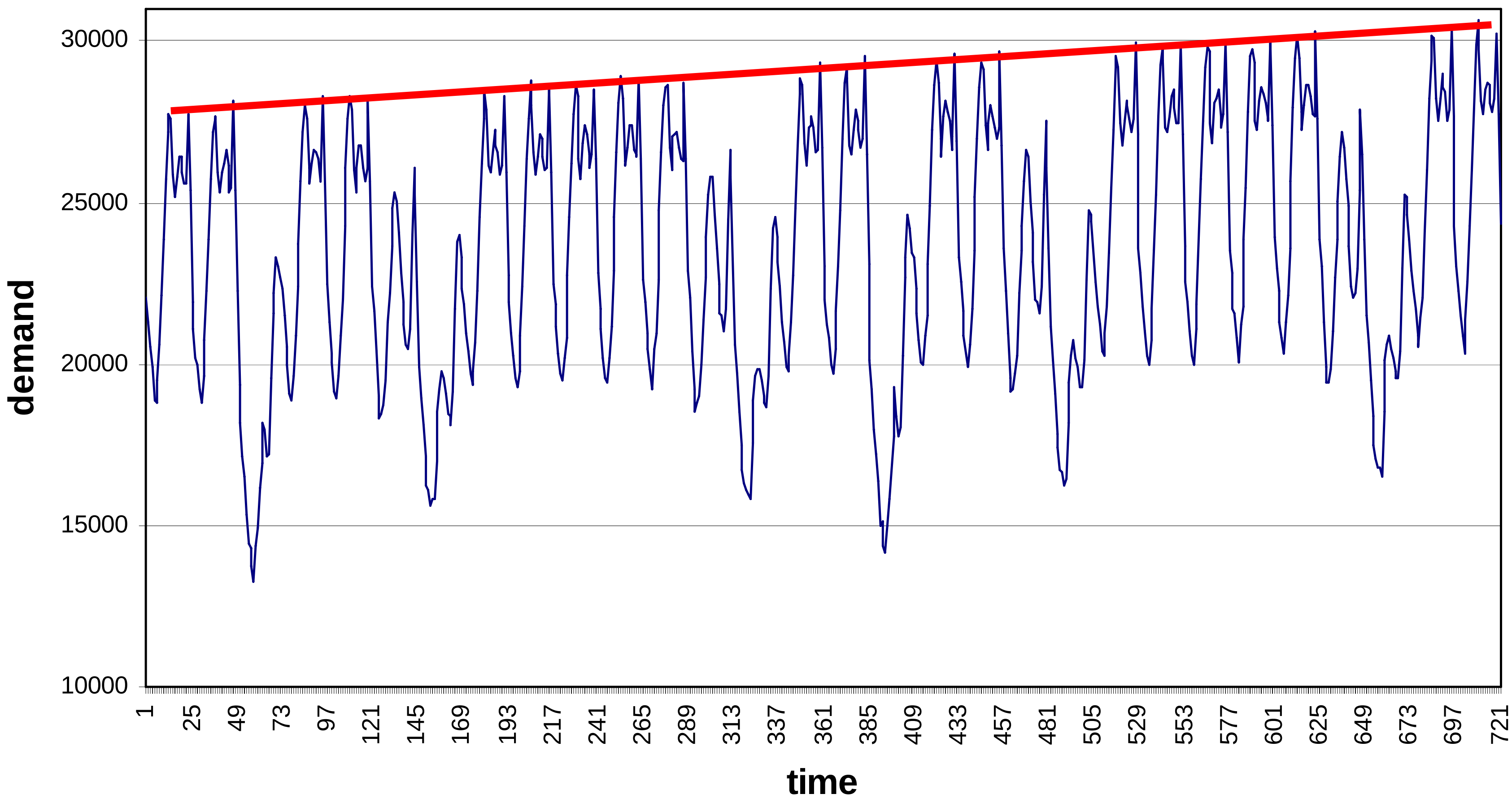
The demand in the EBM



Saturday and Sunday

The demand in the EBM

Step1: EBM



The electrical network system operator

- Mediates between producers and consumers.
- Distributes the demand using the following procedure:

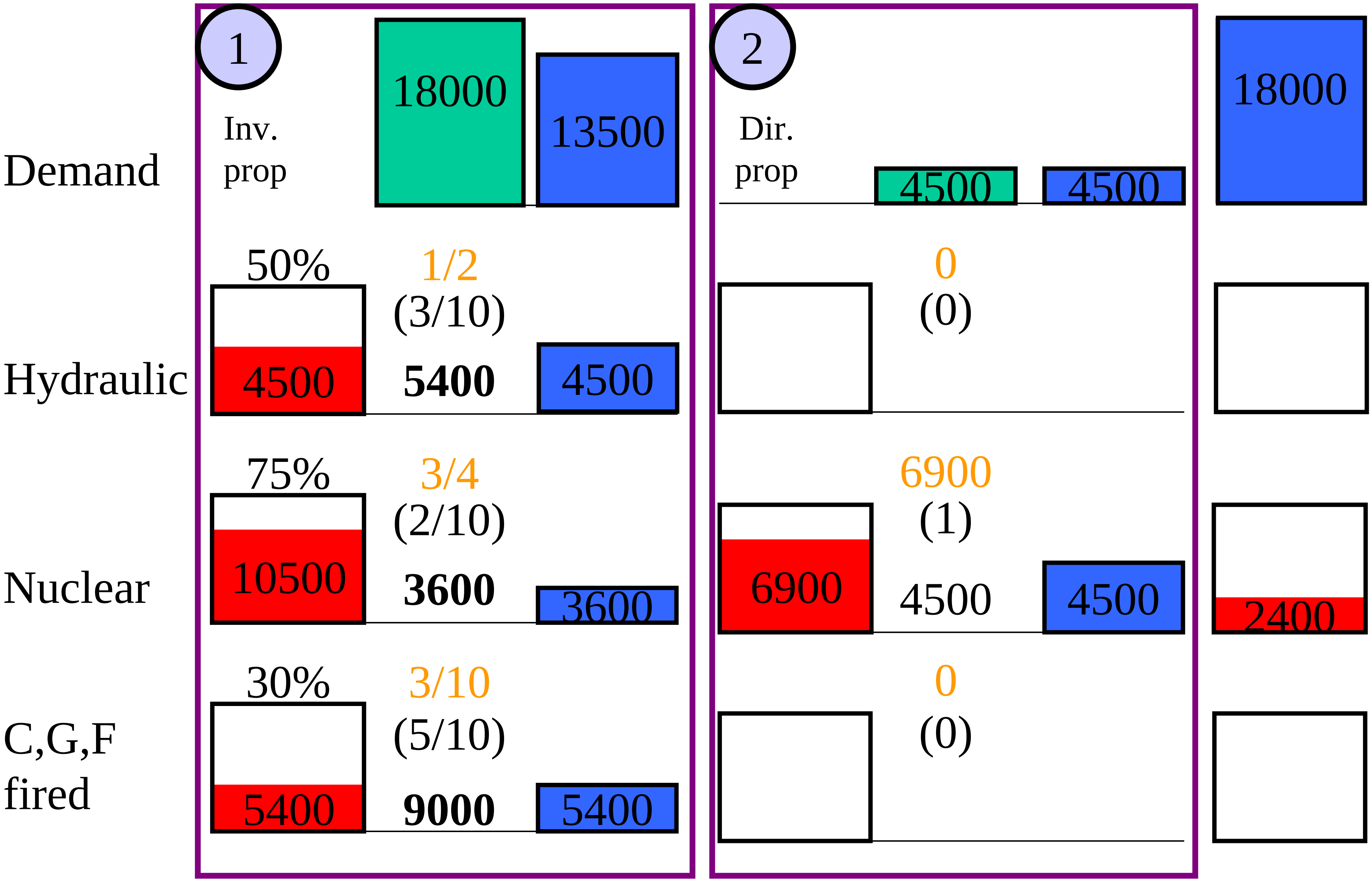
  -If the produced power is **less or equal** than the demand, the SO **takes all the power production** from each producer.

  - If the production is **greater** than the demand, the SO distributes this demand among producers inverse proportion to their efficiency.

  - If there is still demand to be satisfied, then this demand is distributed in **direct proportion to the spear power of each producer**.

The electrical network system operator

Step1: EBM

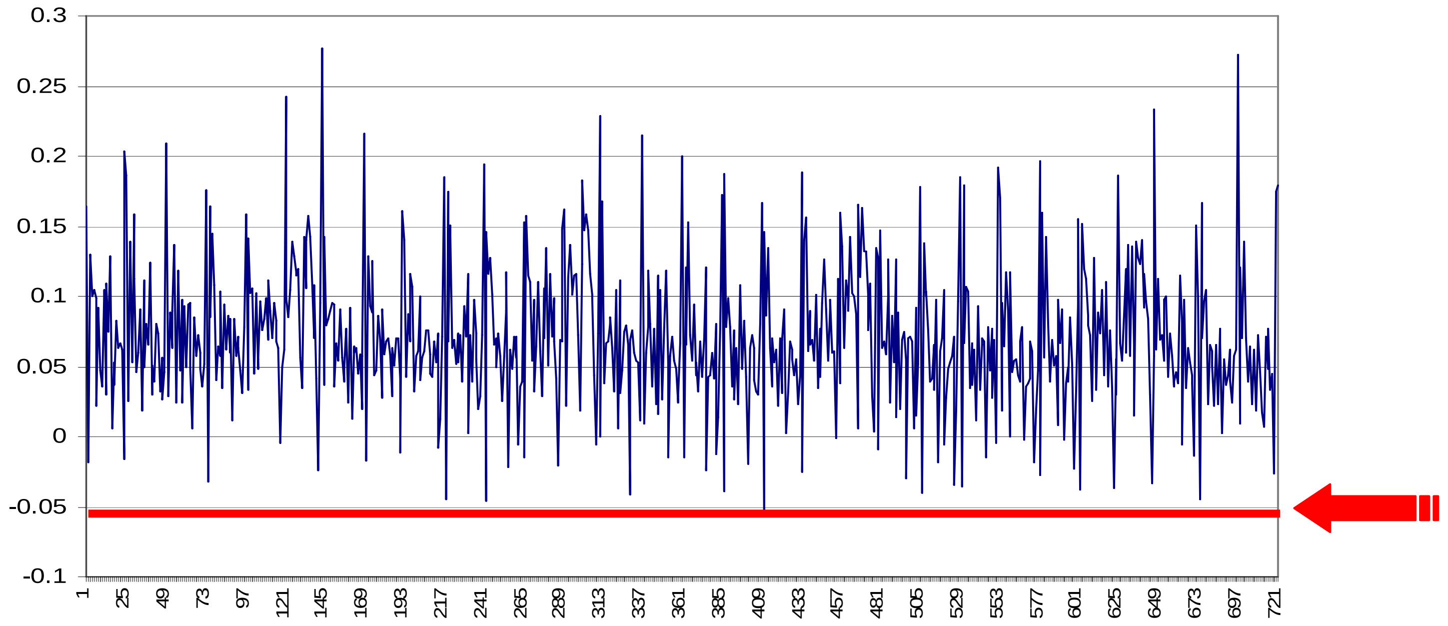


The electrical network system operator

Step1: EBM

- The system operator controls two variables:

  - That the deficit of power be punctual.
  - That the deficit of power never be grater than a 10% of the total production.



Power cost

- The cost of consummed power in the EBM is the total cost of the produced power including overproduction.

- The production cost is the addition of a **maintenance cost** (that does not depend on the quantity of power produced) and the cost of producing each power unit (**generation cost**).

Type	Maintenance cost	Generation cost
Hidroelectric 	72000 €	16 €/MWh
Nuclear 	224000 €	13 €/MWh
C,F,G-fired 	180000 €	20 €/MWh

Power cost

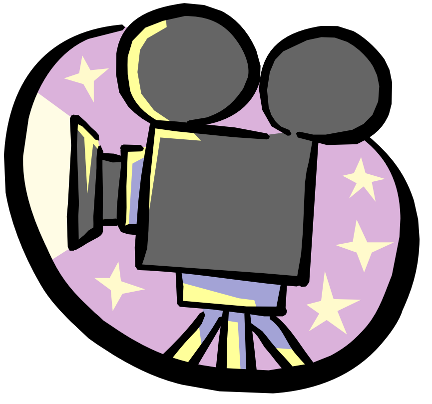
• In the EBM model, the average power cost is

39,16 €/MWh

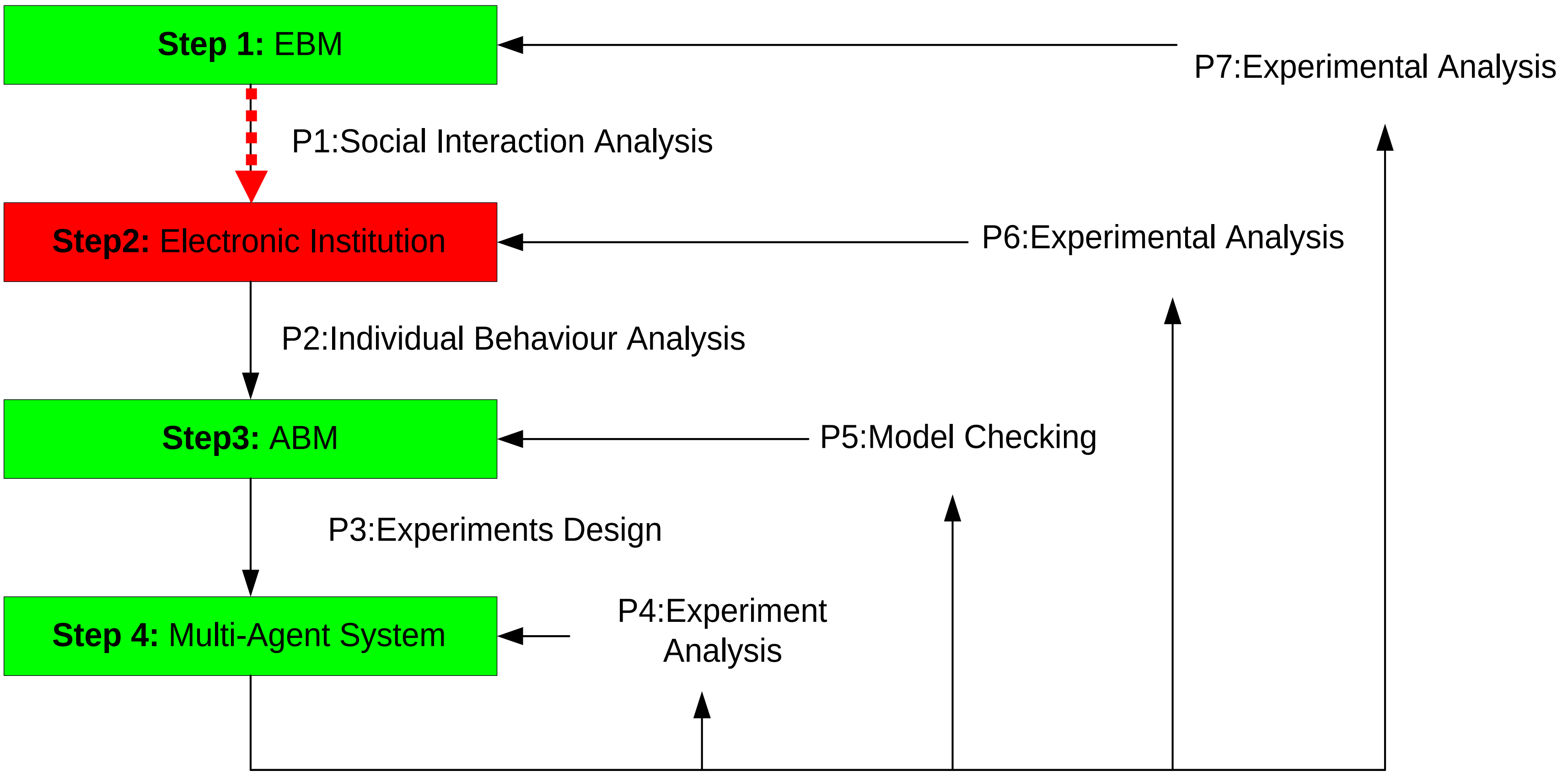
that is very near to the average power cost in Spain in 2002, which was 38,91 €/MWh.

• The power losses in the EBM model (power that is produced but is not consumed) are less than 8% of the consumed power.

EJS



The power market: EI



The power market: EI

• Goal: To put at the same level the demand of power and its generation.

• Two things have to be avoided: lack and excess of production.

• This must be achieved while maintaining a reasonable price per energy unit.

•The power electricity market presented here is based on a New Electricity Trading Arrangements (NETA) proposal presented the October 2000 in the UK.

The power market: EI

Step2: Electronic Institution

Players:

SO

Responsible for:
-Maintaining the supply voltage.
- Maintaining the stability of the system (thermal overload and dynamic security)

PRODUCERS

CONSUMERS

-Hidroelectrical
- C,G,F-fired
- nuclear

Large **industrial processes** and local **power distribution utilities**

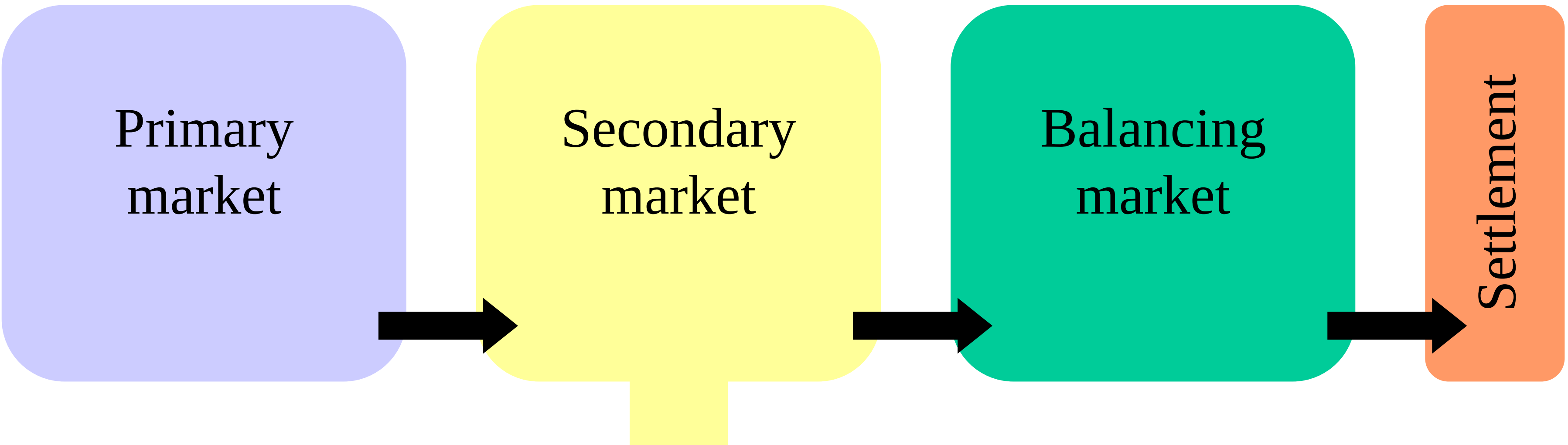
The power market: EI

The scenario:

- Periodic auctions of transmission rights in form of **tickets** valid for the injection or extraction of energy over the next hour.
- Double auction.
- Offer is greater than the demand.

The power market: EI

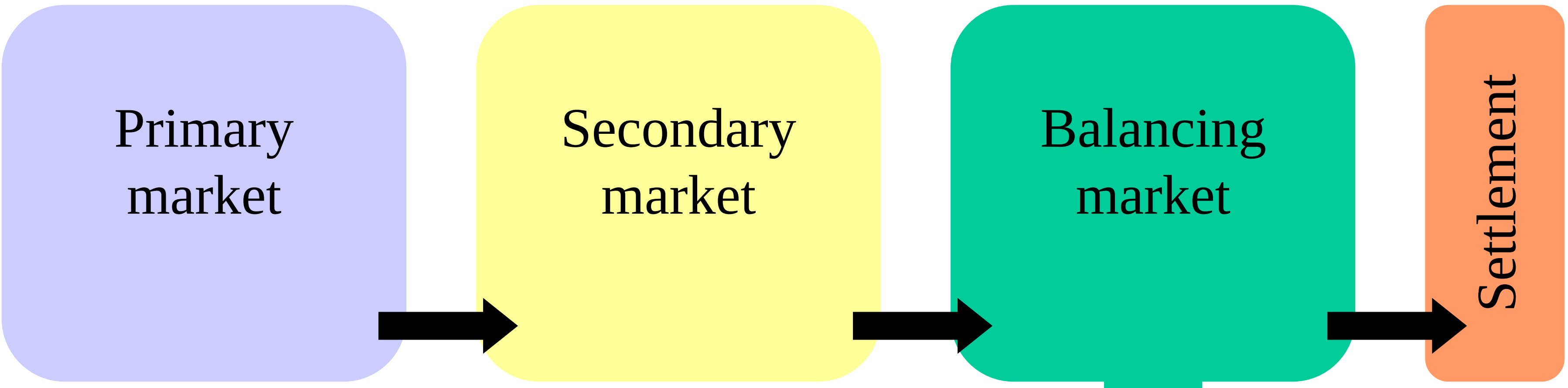
The scenario:



- Secondary market for the trading of transmision **tickets**.
- Lasts until the “gate closure”.
- Negotiation process.

The power market: EI

The scenario:

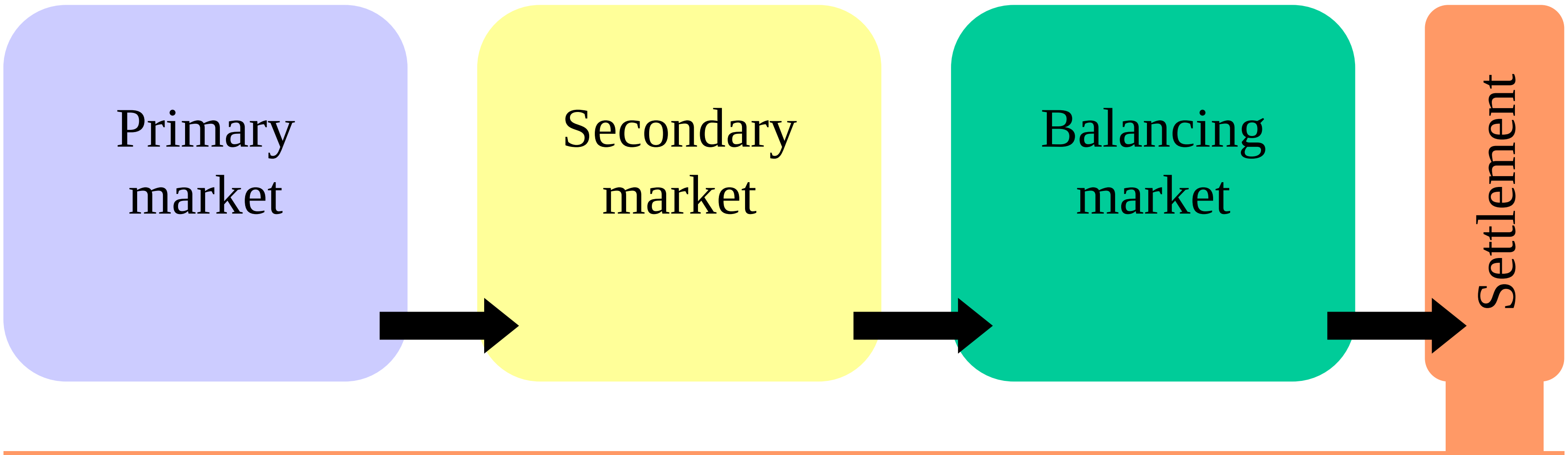


- Allows the SO to maintain the voltage level and dynamic security.
- The SO can identify shortfalls or excesses of energy that will arise in the ticket window.
- The SO can: (i) dispatch additional generation,
  (ii) back-off scheduled generation.

The power market: EI

Step2: Electronic Institution

The scenario:



- Consumers pay producers for the power consumed.

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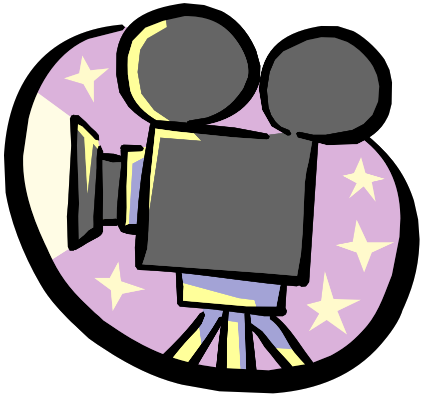
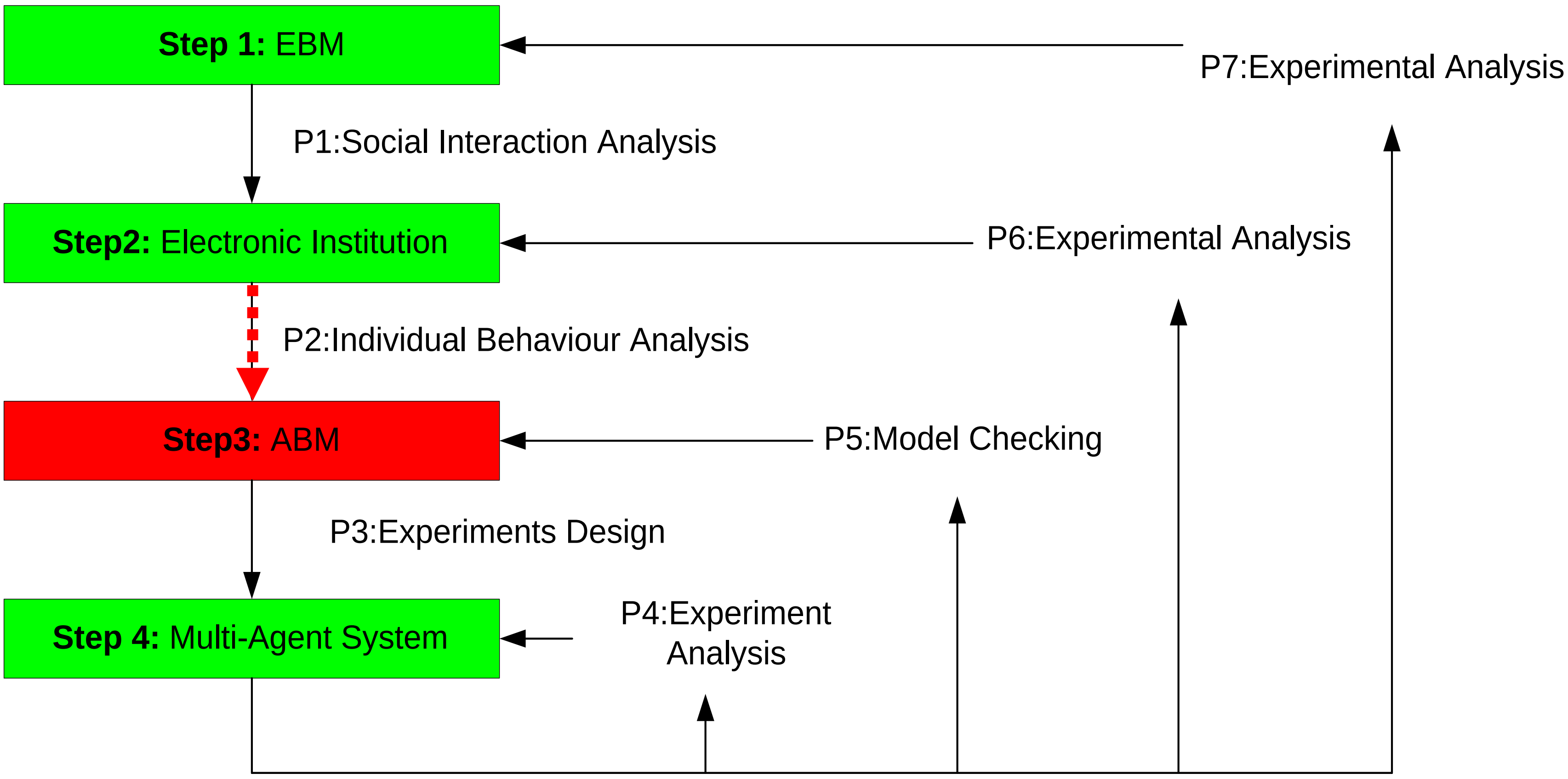
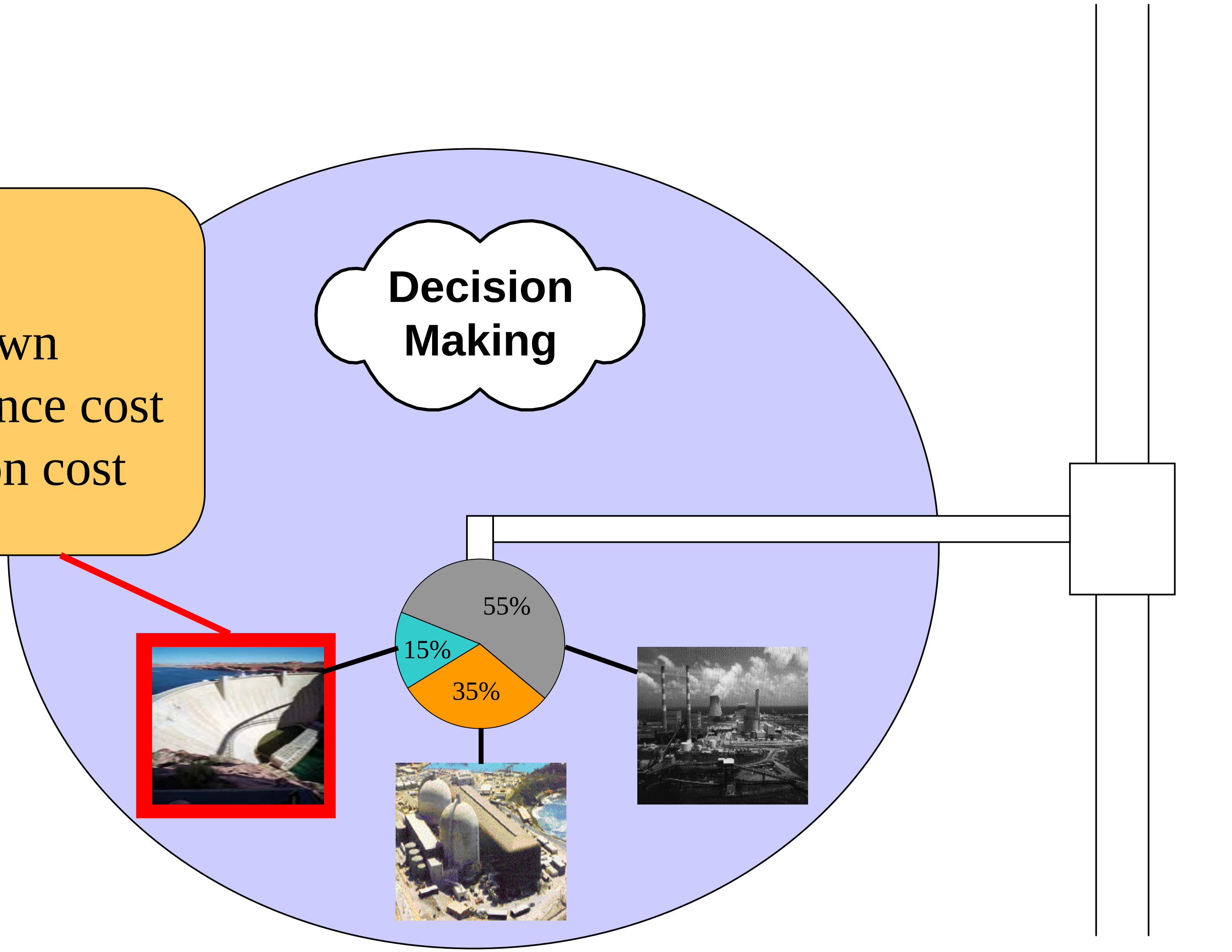


The power market: ABM

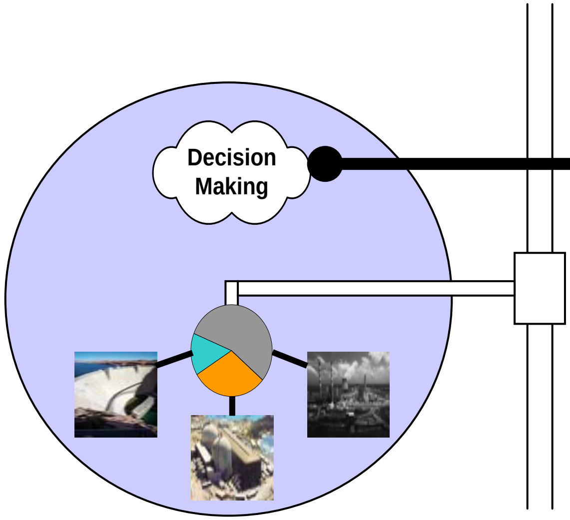


Producer

- PowerUp
- PowerDown
- Maintenance cost
- Generation cost

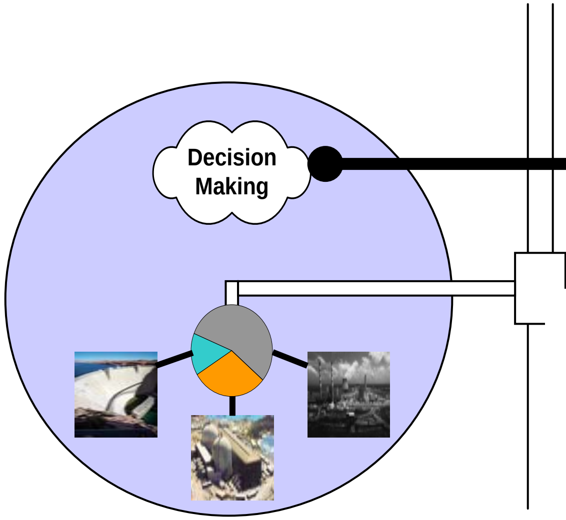


Producer



- The amount of power that will be generated during the next half an hour.
- The price and quantity of the power offered in the primary market.
- The price and quantity of the power offered in the secondary market.

Producer

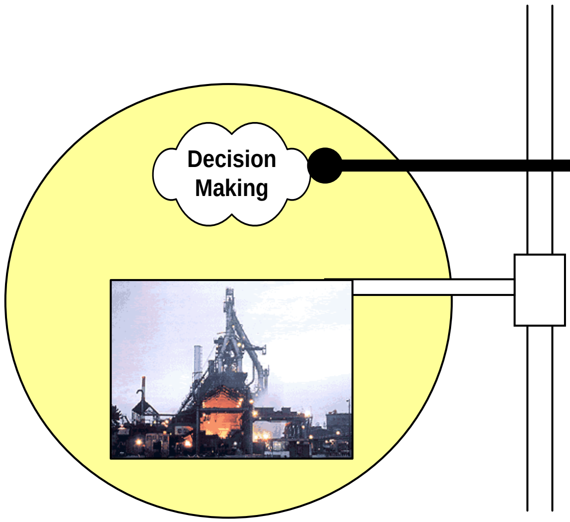


$$Q^t = \begin{cases} Q^{t-1} + PowerUp & lastSold = true \\ Q^{t-1} - PowerDown & lastSold = false \end{cases}$$

$$P^t = \begin{cases} P^{t-1} + \varepsilon^{+} \cdot \frac{|P^{t-1} - AvP^{t-1}|}{AvP^{t-1}} & lastSold = true \\ P^{t-1} - \varepsilon^{-} \cdot \frac{|P^{t-1} - AvP^{t-1}|}{AvP^{t-1}} & lastSold = false \end{cases}$$

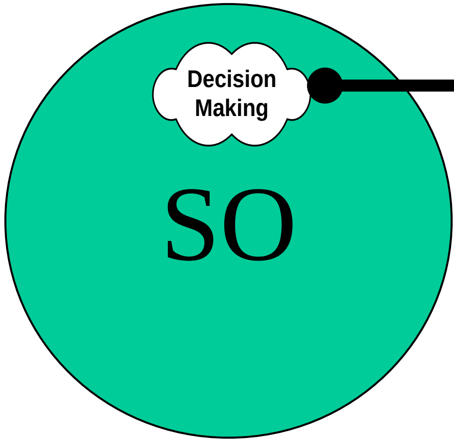
$$FinalP^t = min(P^t, \text{Production\_cost})$$

Consumer



- The demand of energy for the next Half an hour.
- The price and quantity of the power demand in the primary market.
- The price and quantity of the power demand in the secondary market.

System operator

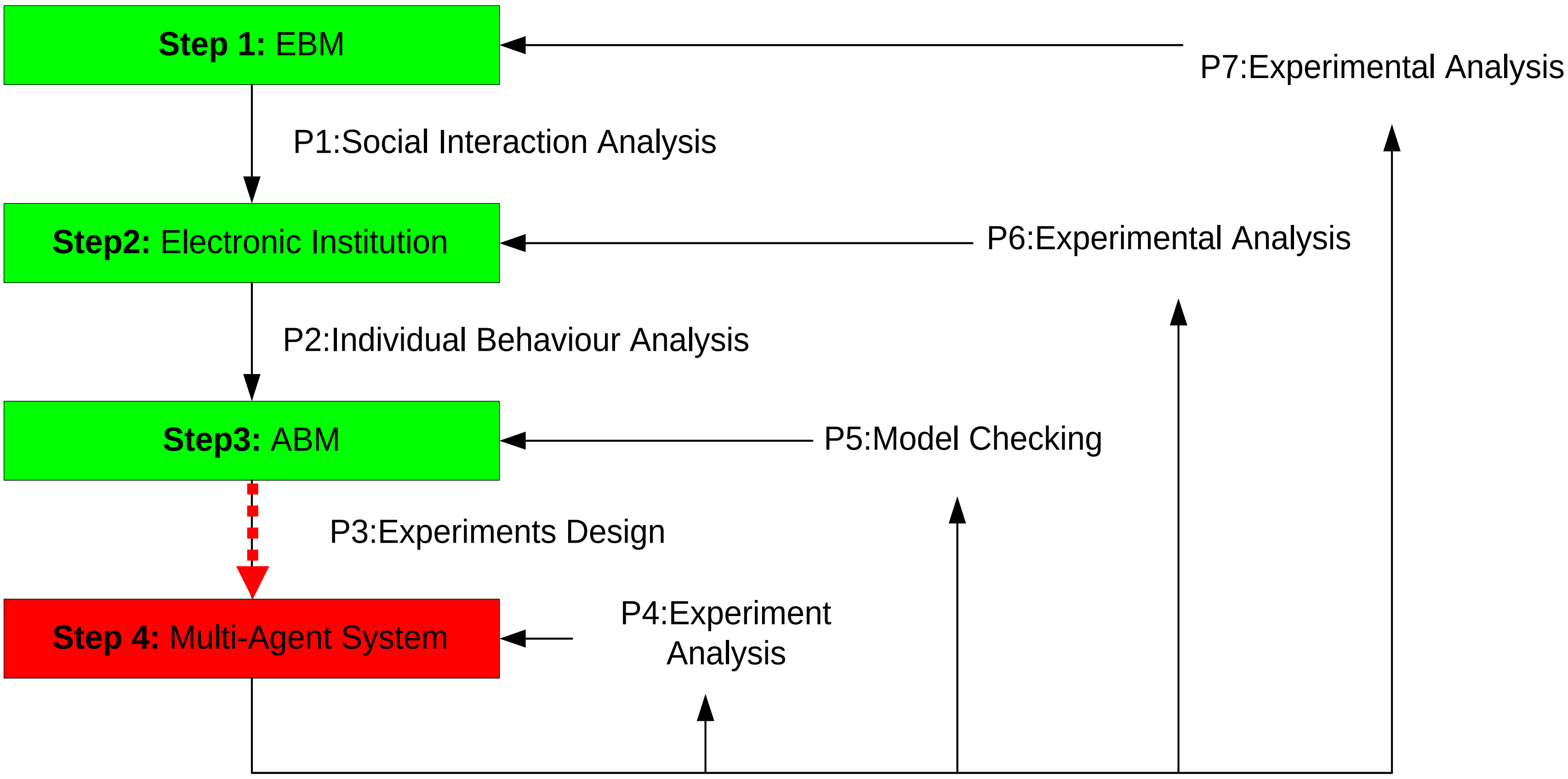


- After the primary and secondary markets there are two possible Situations:

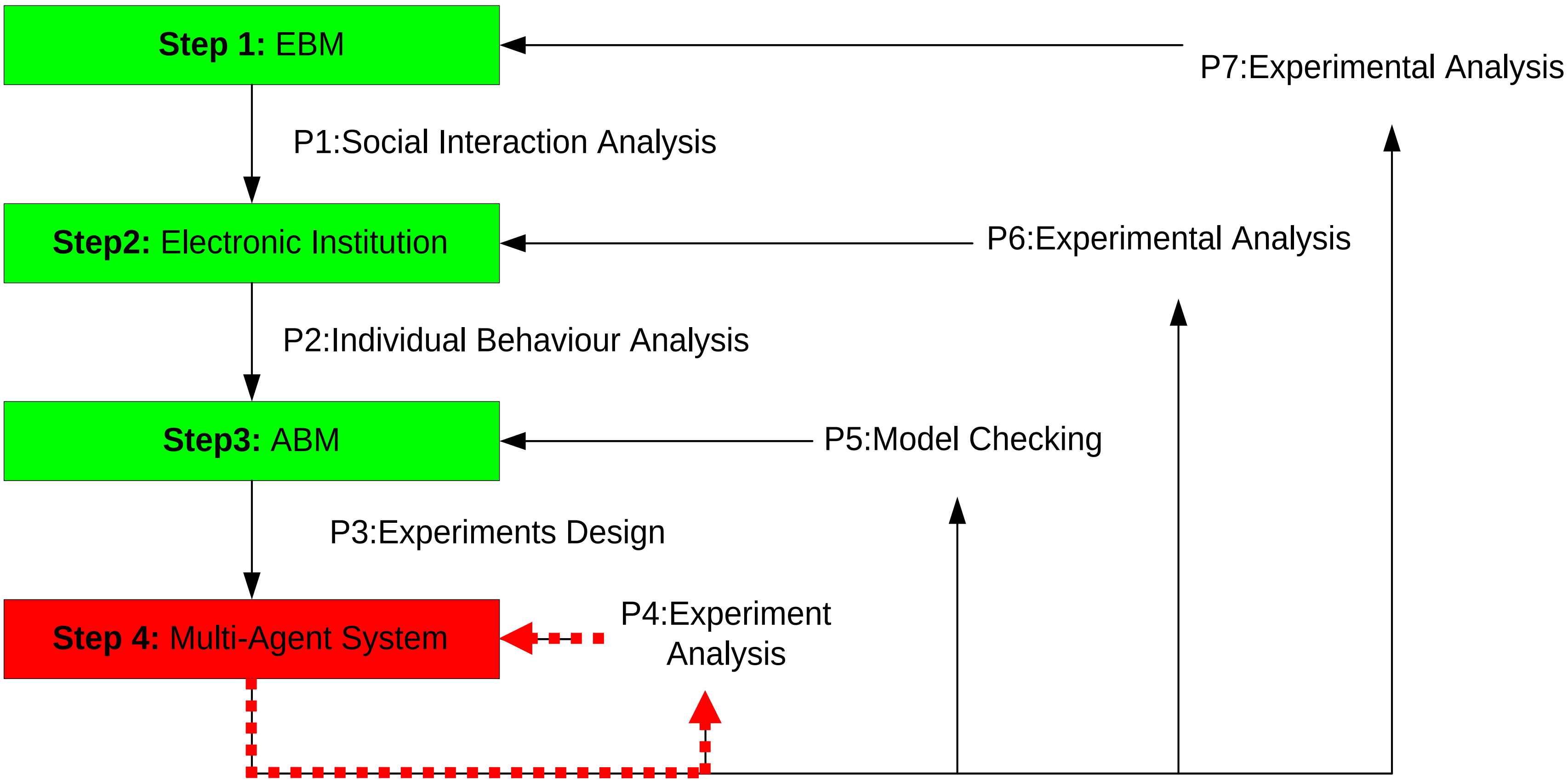
  - The demand has been covered in the primary and secondary markets.

  - There is some demand that has not been covered.

The powermarket: Multi-agent System

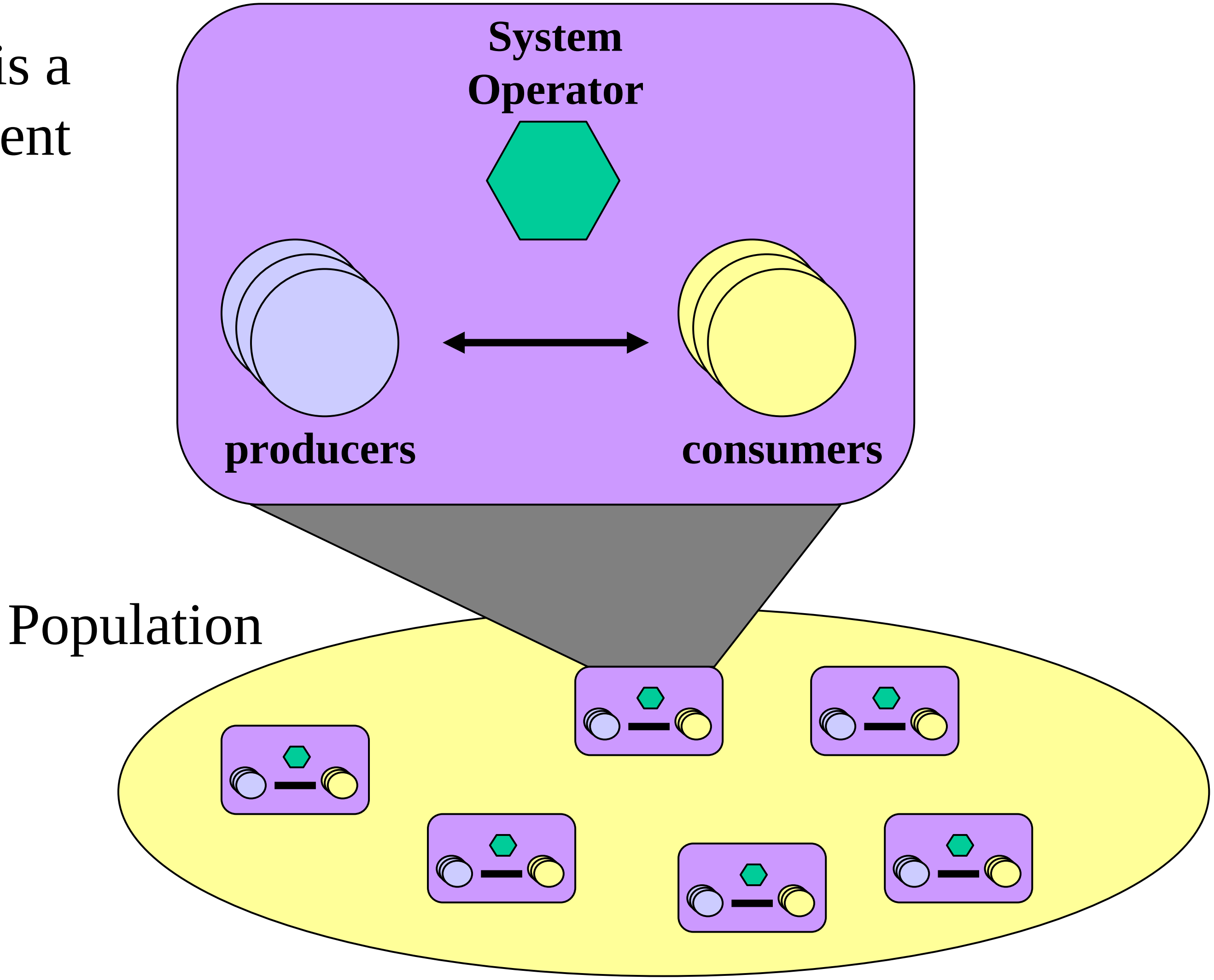


Evolutionary computing within SADDE



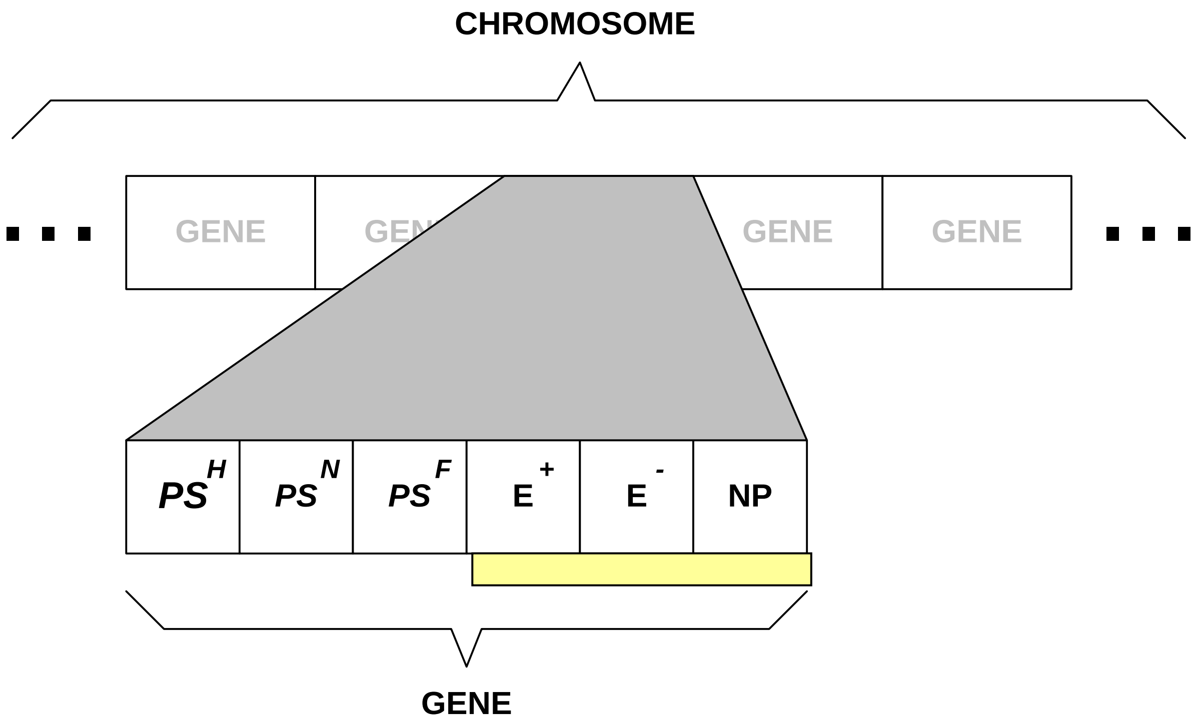
Genetic representation

- Each individual is a complete multi-agent system.



Genetic representation

• One gene in a chromosome represents one agent in the multi-agent system.



PS parameters: each one represents a different type of power station
E+,E- define the strategy of the producer to fix the prices in the DA
NP the price the producer will offer in the secondary market

Technical aspects

- EO evolutionary computation framework
  - template-based, ANSI-C++ compliant evolutionary computation library.
- PVM
  - Software package that permits a heterogeneous collection of UNIX and/or Windows computers hooked together by a network to be used as a single large parallel computer.
  - All genetic operations in a single computer
  - Master computer distributes individuals to be evaluated at the computers composing the virtual machine

Experiment 1

Experiment - 1

• Goal: To find a MAS that converges with the EBM in three aspects:

-Average power price in the market during the analyzed period (720 hours = 1 month).

EBM: 39,16

- Percentage of demand relative to the produced energy that cannot be fulfilled.

EBM: <= 3%

- The % of lost power (power that is generated but it is not consumed)

EBM: ~ 8%

Experiment – 1. Fitness functions

$$f1 = ac\left(\frac{100 \cdot |AvABM - AvEBM|}{AvEBM}\right)$$

This function computes how near is the average cost of the electricity produced in the MAS ($AvABM$) with the average cost of the electricity we have calculated using the EBM ($AvEBM$). The ac function is defined as:

$$ac(x) = \begin{cases} 1 & \text{IF } x < 8 \\ 1 + \frac{(8-x)}{7} & \text{IF } 8 \leq x \geq 15 \\ 0 & \text{OTHERWISE} \end{cases}$$

$$f2 = ed\left(\frac{100 \cdot PowerDeficit}{Production}\right)$$

This function computes the percentage of power deficit relative to the total production. The ed function is defined as:

$$ed(x) = \begin{cases} 1 & \text{IF } x < 1 \\ \frac{(3-x)}{2} & \text{IF } 1 \leq x \geq 3 \\ 0 & \text{OTHERWISE} \end{cases}$$

$$f3 = pl\left(\frac{100 \cdot PowerLost}{Production}\right)$$

This function evaluates the power lost in our model (power that is produced but is not consumed). The pl function is defined as:

$$pl(x) = \begin{cases} 1 & \text{IF } x < 8 \\ \frac{(10-x)}{2} & \text{IF } 8 \leq x \geq 10 \\ 0 & \text{OTHERWISE} \end{cases}$$

Experiment - 1

- **PARAMETERS:**

  50 individuals per population
  0.1 crossover probability
  0.05 mutation probability

  30 producers, 60 consumers
  720 rounds (~1 month)

- **Termination** condition:

  The average fitness after 15 executions of the best individual must be greater than 0.9.

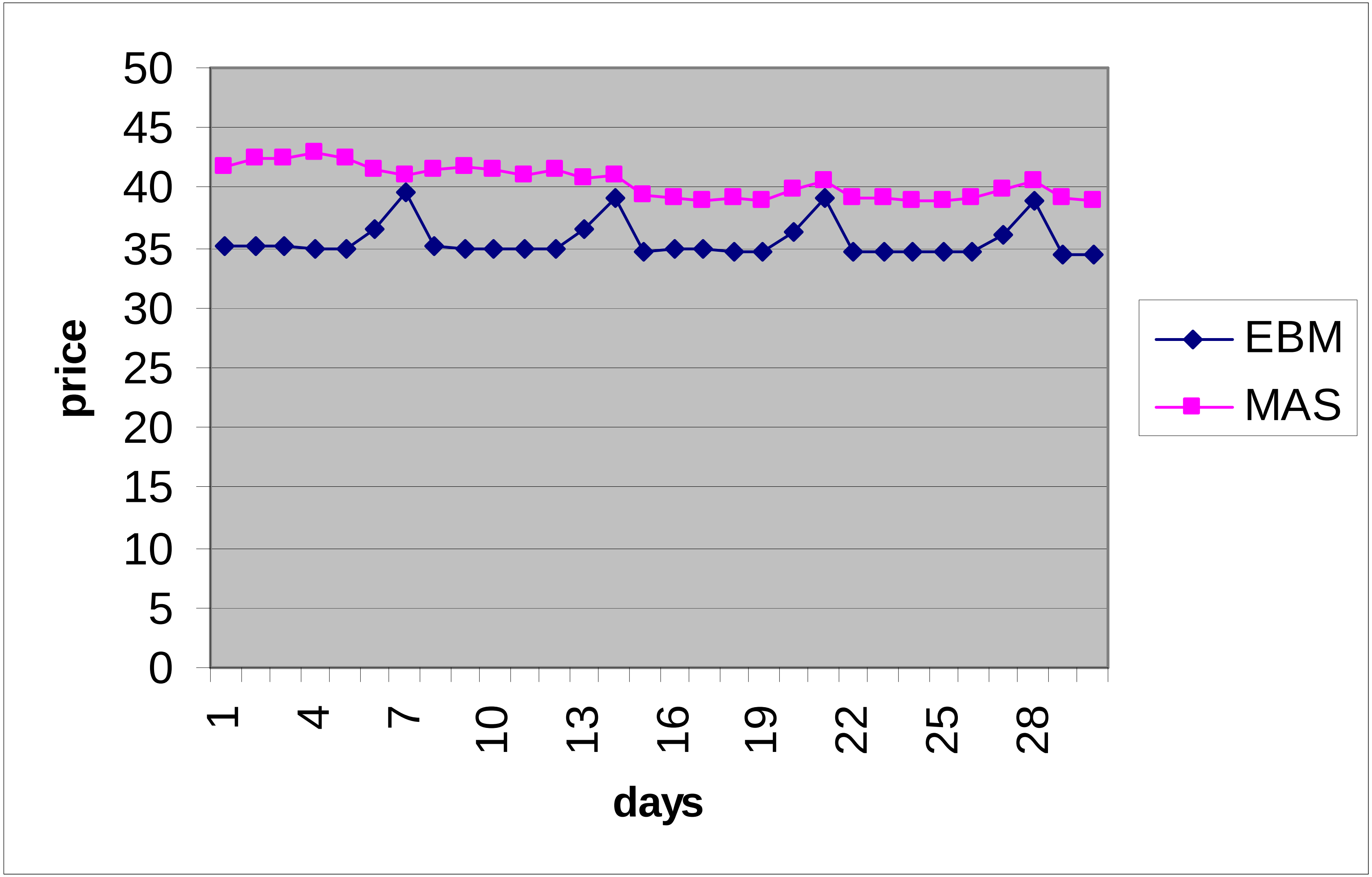
  The minimum fitness after this 15 executions must be grater than 0.7.

Experiment - 1

- RESULT:

  In all the performed experiments, after about 25-30 generations the genetic algorithm was able to find an individual with the required conditions.

Experiment - 1



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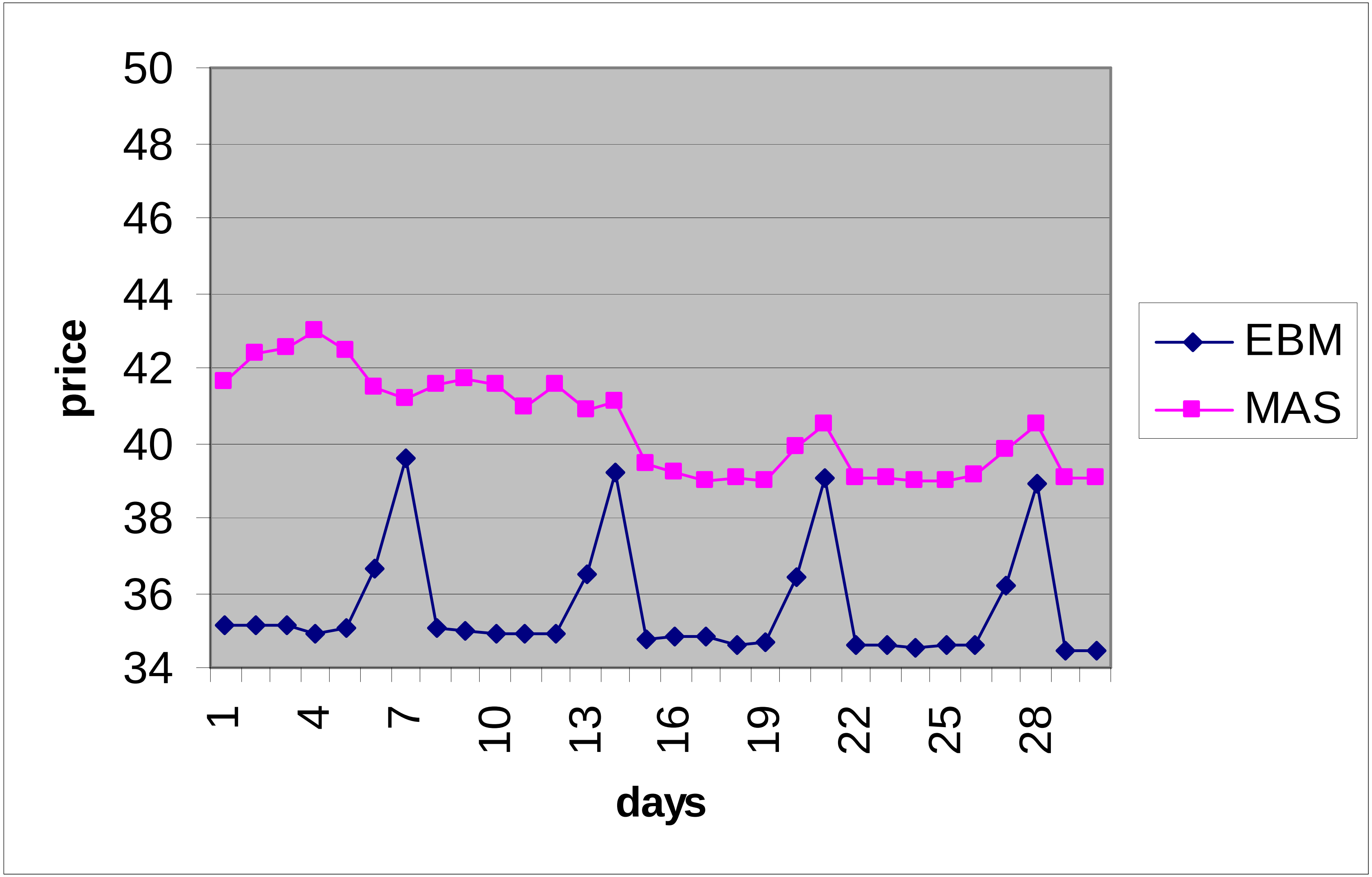

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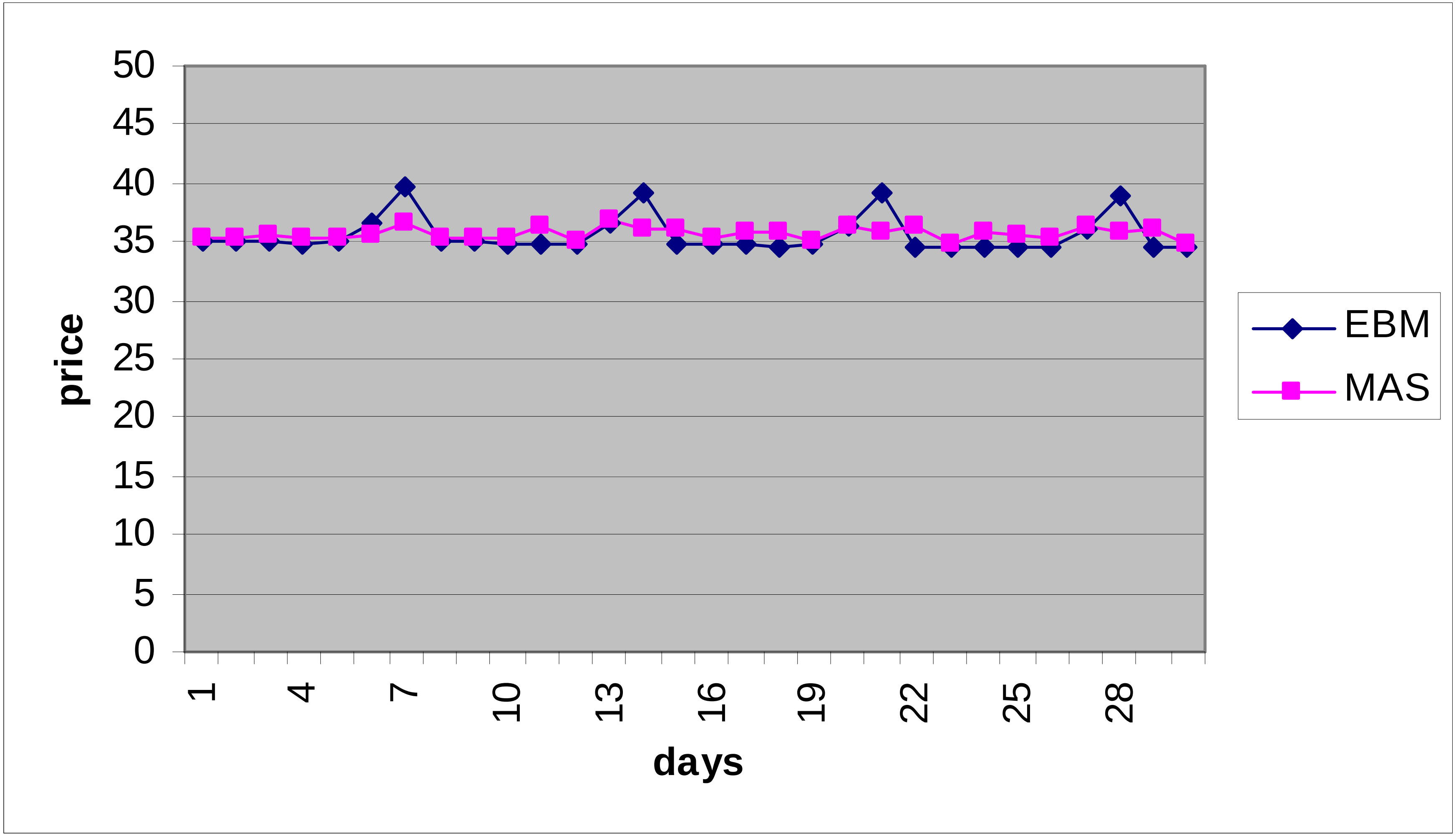
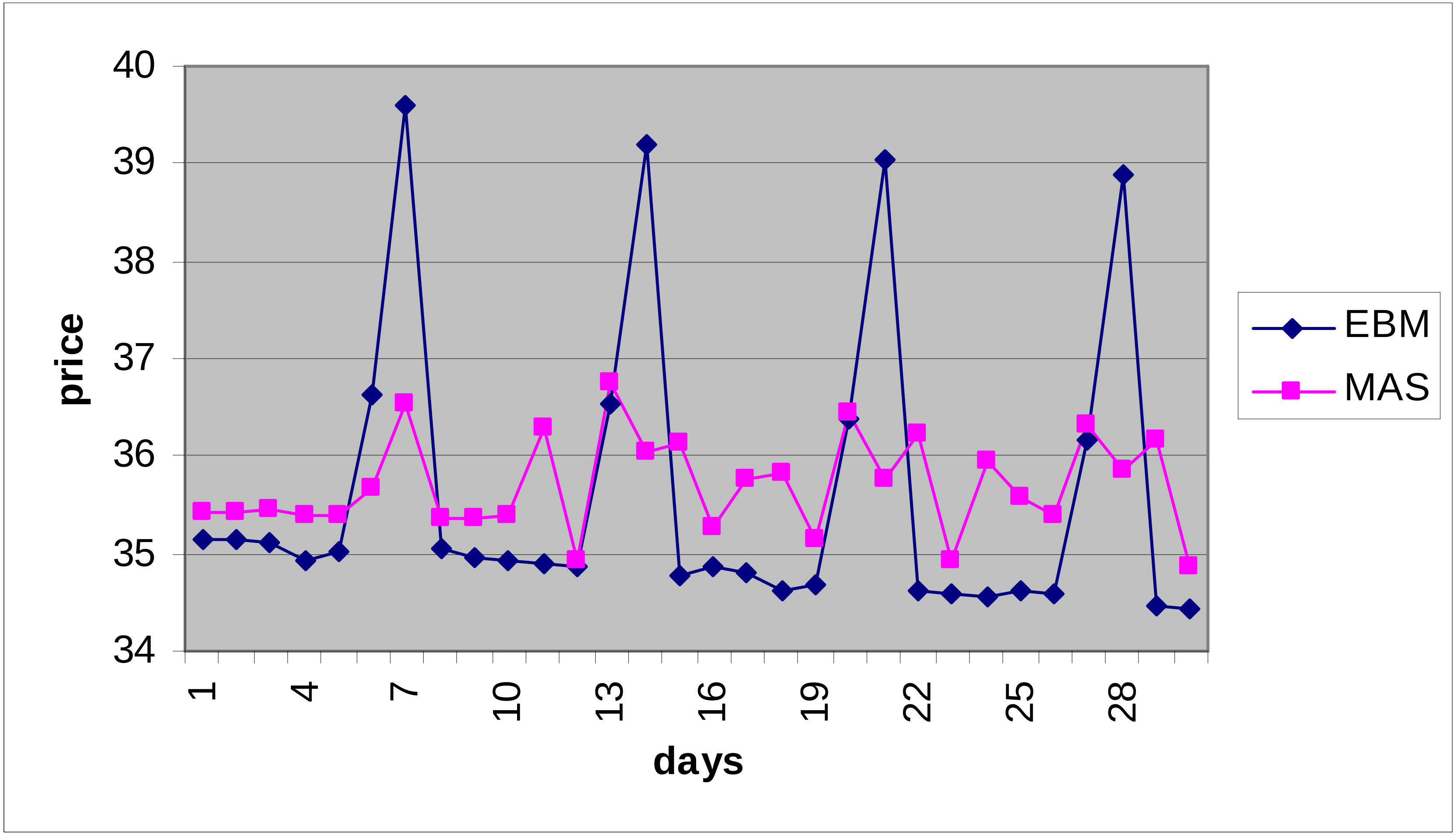


Experiment - 1



A real multi-agent system

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