Some Challenging Problems in Energy Management

Riadh ZORGATI
EDF R&D Division, OSIRIS

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LEADING THE ENERGY CHANGE

OUTLINE

Introduction - EDF : Electricité de France

Part I : Energy Management & Optimization

1. Energy Management : The Industrial Context
2. Some Challenging Features of Energy Management Optimization Problems

Part II : Some Challenging Problems

3. At Mid Term : a) Equilibrium b) Nuclear Outages Scheduling
4. At Short Term : Daily & Intra-Day Unit Commitment
5. Smart Grids & Optimization

Conclusions

Introduction

EDF : Electricité de France

The World Electrical Market : Context

A new world. **4** major changes **:**

- Big cities : 50 % of population live in towns, 70 % in 2050
- Finite ressources and need to « de-carbon » energy
- Emerging Countries : China, Brazil, India…
- Local setting : town systems, local energy, network and smart grids

Chiffres clés

Sources AIE

1/3

of energetical needs are covered by the electrical production

40 %

Of electricity in the world comes from **coal**, 20 % from natural **gas**, 16 % from hydro,15 % from nuclear, 7 % from oil and 2 % from renewable energy

EDF : a world leader in energy

37.9 million
of customers in the world

169 139
employees in the world

66.3 Md€
Turn Over
(49 % outside France)

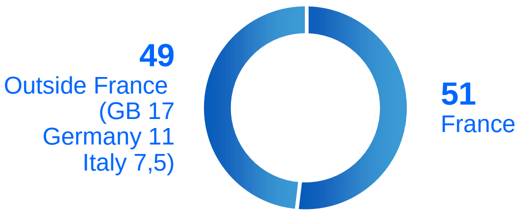
618.5 TWh
produced in the world

117.1 g
of CO_2 per kWh produced

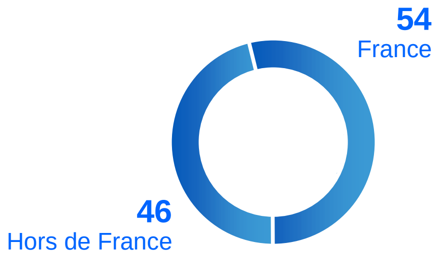
- Electricity : production, transportation, distribution and trading
- **In Europe** : France, GB, Germany, Italy…
- Industrial Operator in **Asia** and in the **USA**
- Natural Gas : an important actor

Chiffres clés

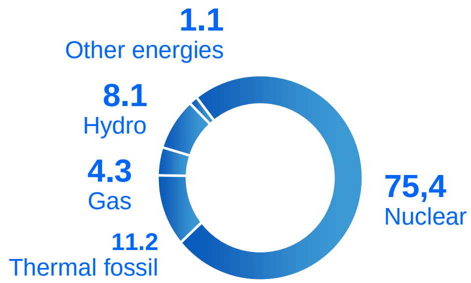
Turn Over 2009
in %



EBITDA 2009
In %



Mix of production 2009
In %



Total : 618.5 TWh

EDF in Europe

Mainly in …

France
- **EDF – RTE-EDF Transport,** EDF 100 %
- **ERDF,** EDF 100 %
- **Groupe PEI,** EDF 100 %

GB
- **EDF Energy,** EDF 100 %

Germany
- **EnBW,** EDF 46,07 %

Italy
- **Edison,** EDF 48,96 %
- **Fenice,** EDF 100 %

And in …

Autriche
- **Groupe ESTAG**, EDF 25 %

Belgium
- **EDF Belgium**, EDF 100 %
- **SPE**, EDF 51 %

Spain
- **Elcogas**, EDF 31,39 %

Hungary
- **BE ZRt**, EDF 95,57 %
- **EDF DÉMÁSZ**, EDF 100 %

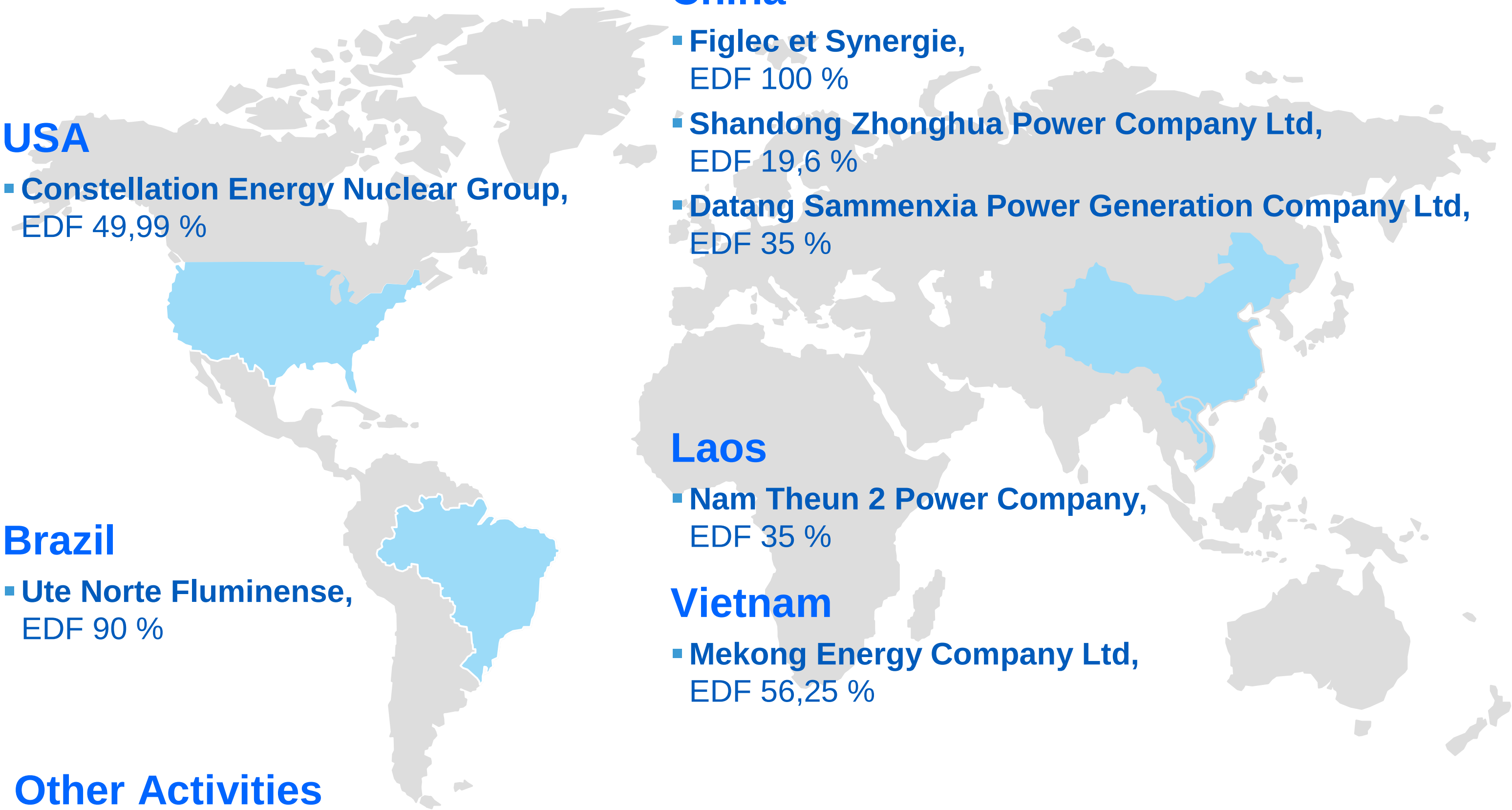
Nederlands
- **SloeCentrale BV**, EDF 50 %

Slovacia
- **SSE**, EDF 49 %

Switzerland
- **Alpiq**, EDF 26,06 %

Poland
- **EC Wybrzeze**, EDF 99,73 %
- **Elektrownia Rybnik SA**, EDF 79,76 %
- **EC Krakow**, EDF 94,31 %
- **Kogeneracja**, EDF 40,58 %
- **Zielona Gora**, EDF 39,93 %

EDF in the World



USA

- **Constellation Energy Nuclear Group,**
  EDF 49,99 %

Brazil

- **Ute Norte Fluminense,**
  EDF 90 %

China

- **Figlec et Synergie,**
  EDF 100 %
- **Shandong Zhonghua Power Company Ltd,**
  EDF 19,6 %
- **Datang Sammenxia Power Generation Company Ltd,**
  EDF 35 %

Laos

- **Nam Theun 2 Power Company,**
  EDF 35 %

Vietnam

- **Mekong Energy Company Ltd,**
  EDF 56,25 %

Other Activities

EDF Énergies Nouvelles
- EDF 50 %

Tiru
- EDF 51 %

Électricité de Strasbourg
- EDF 89,07 %

Dalkia
- EDF 34 %

EDF Trading
- EDF 100 %

EDF

Part I :

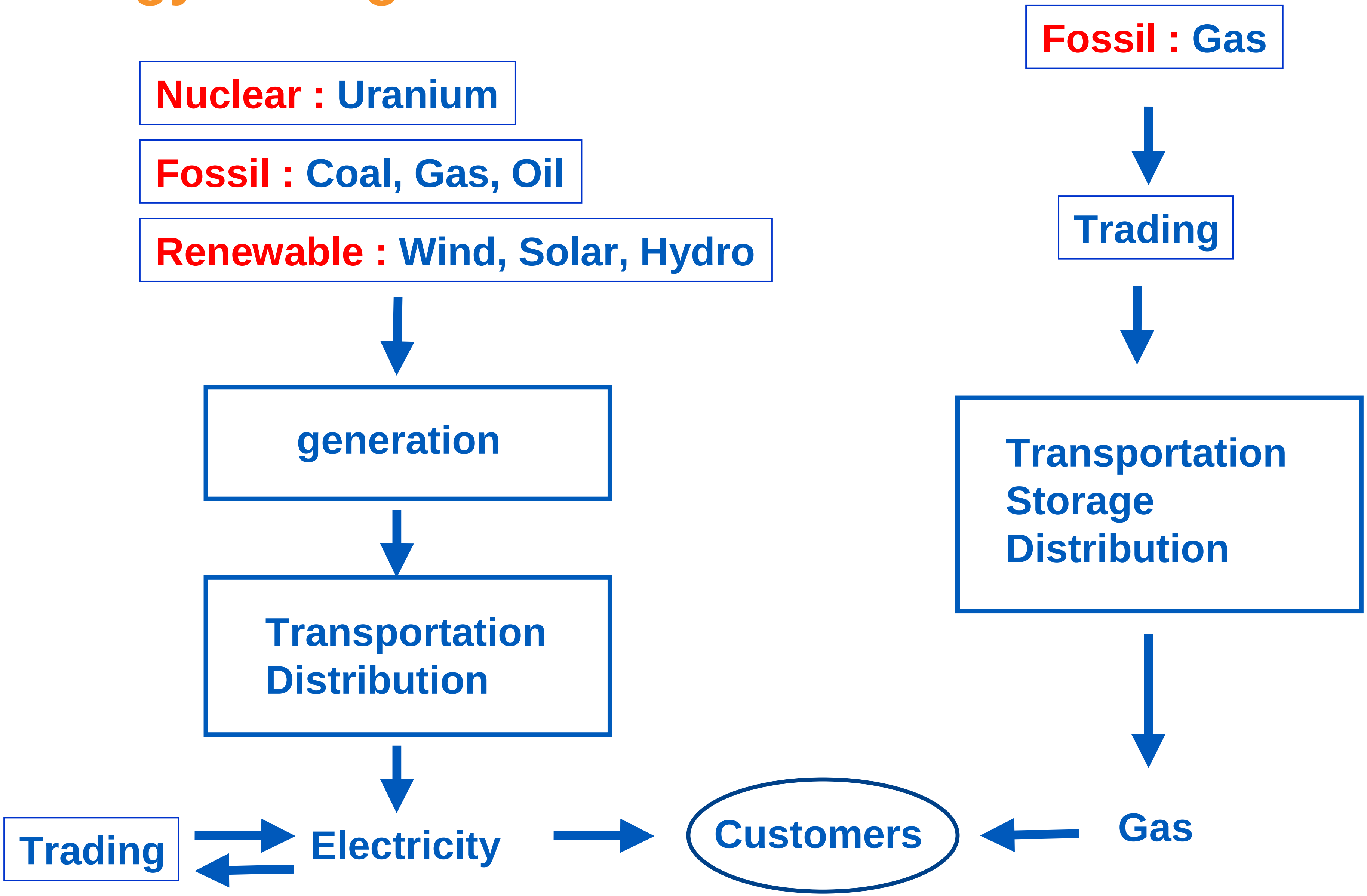
Energy Management & Optimization

1

Energy Management :

The Industrial Context

Energy Management



Electricity Management

Long Term

. Investments & Structure of Production Set
. Prices of Commodities : (uranium, coal, gas, oil)

Mid-Term (MT)

Short-Term (ST)

Pluri-Years

Scheduling Nuclear Power Plants Outages for Refueling & Maintenance

Yearly

. Stocks Management
. Fuel Supply
. MT Hedging
. Risk Management

Weekly

. Security Analysis
. ST Hedging
. Planning of thermal maintenance
. Interruption Options

Daily

. Planning of production

Hourly

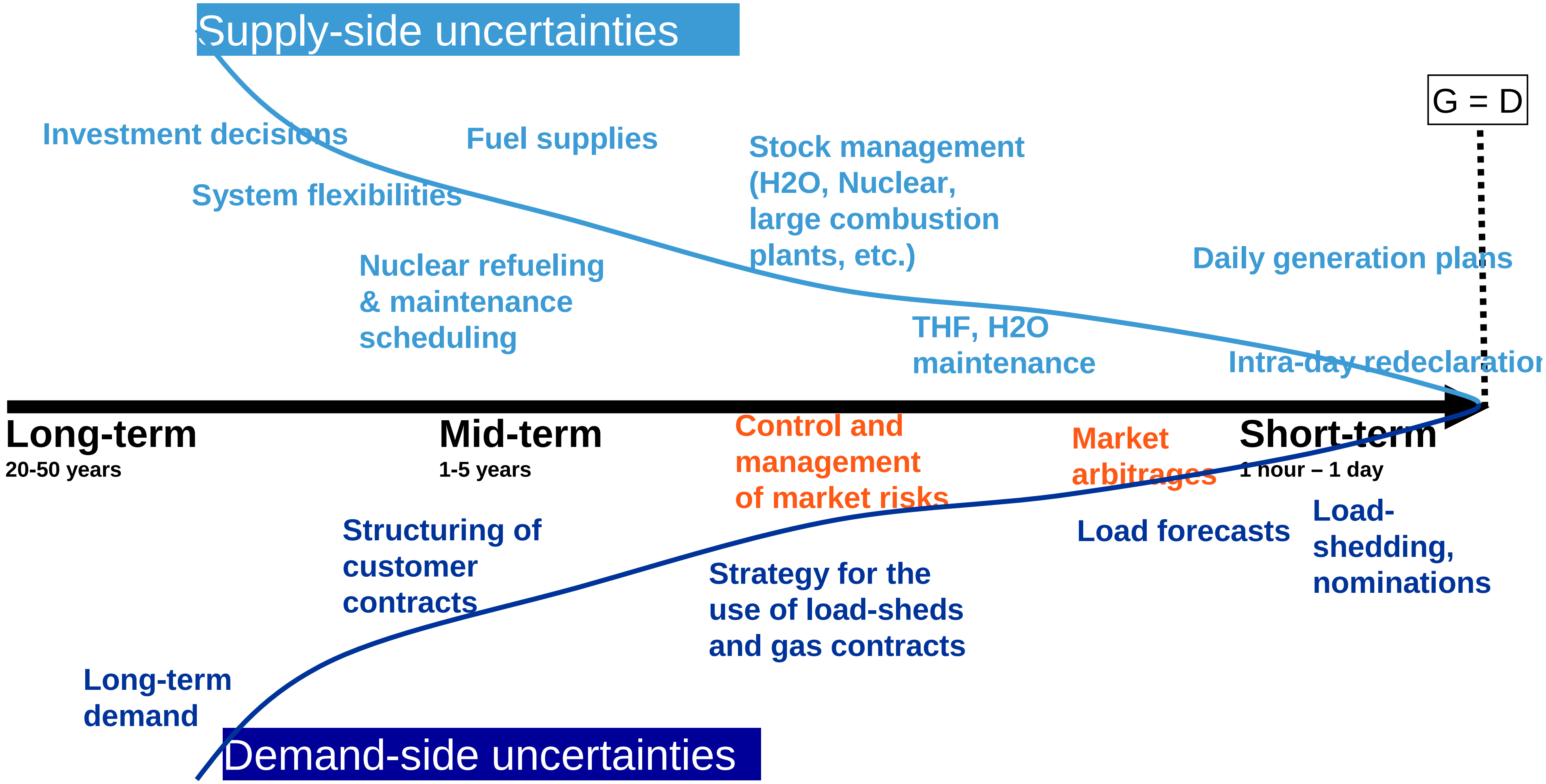
. Recourse

Production Set

Markets

EDF

Electricity Management



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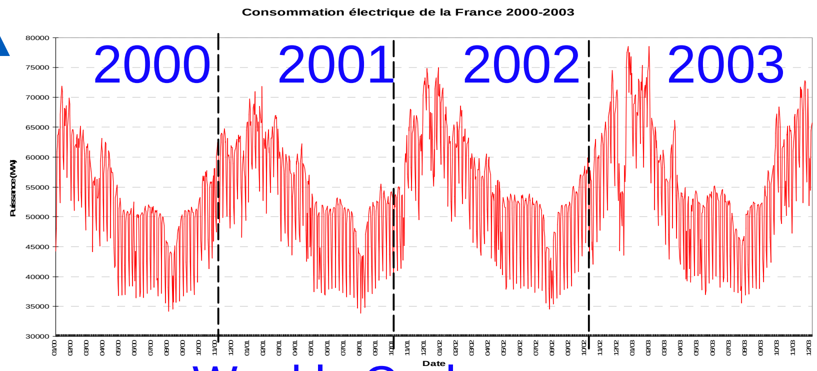
The Demand (Constraint I)

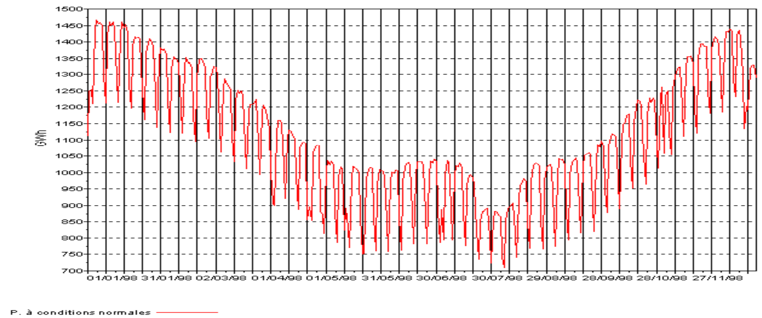
Customer Profiles, exchanges/sales, network losses, own consumption

→ time series with yearly, weekly, daily cycles and yearly trend.

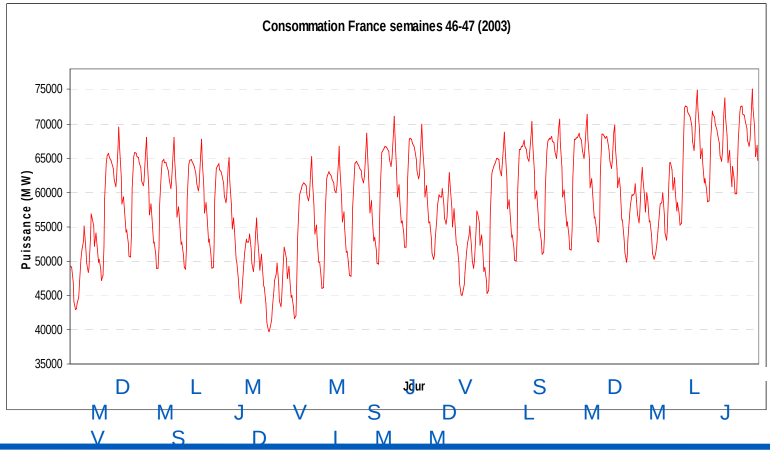
$D_i(\xi_\delta)[MW]$



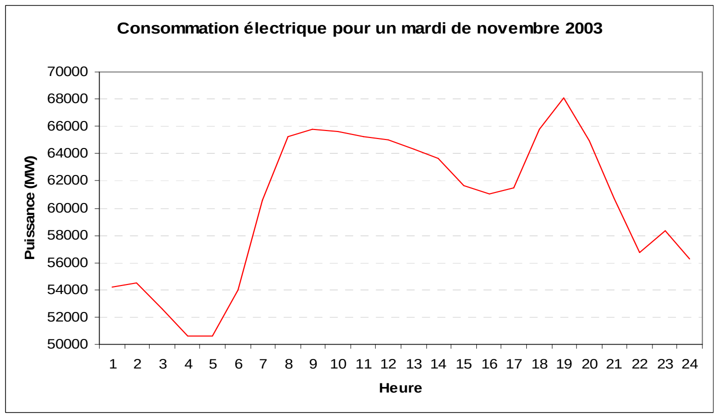
Yearly Cycle



Weekly Cycle



Daily Cycle

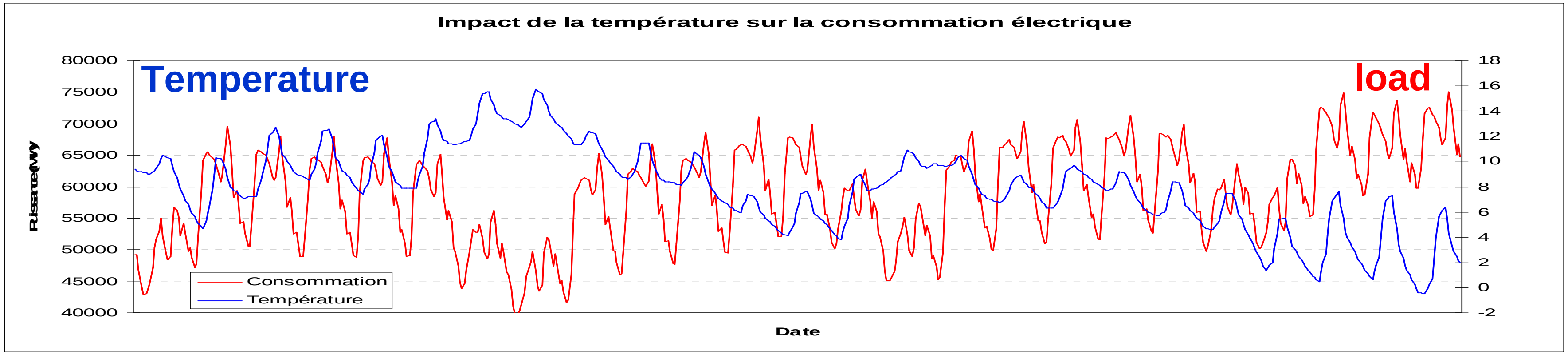


i

Time

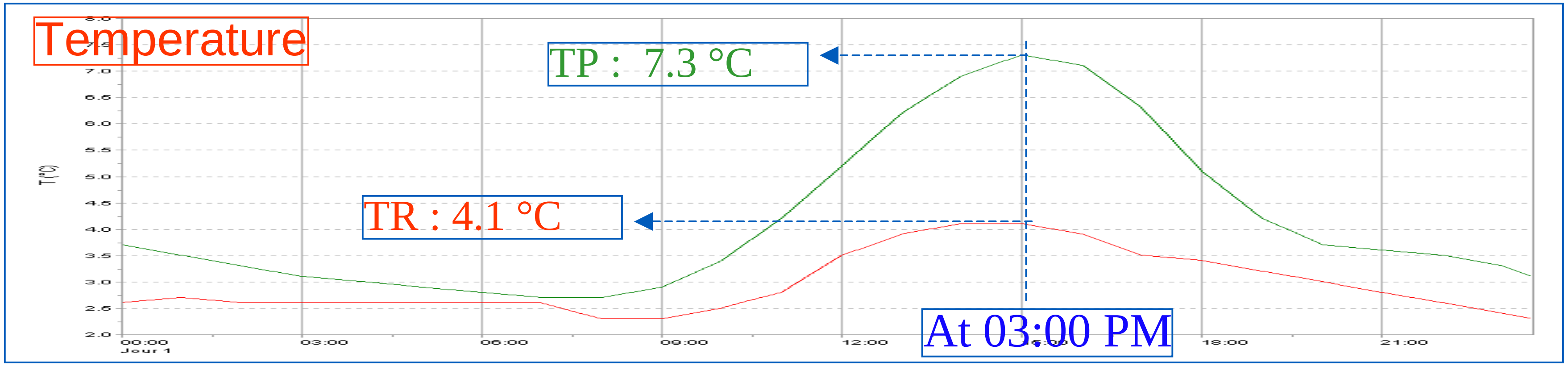
The Demand : Uncertainties (Constraint I)

1. Temperature : Strong influence on Load In winter : -1°C → + 1500 MW



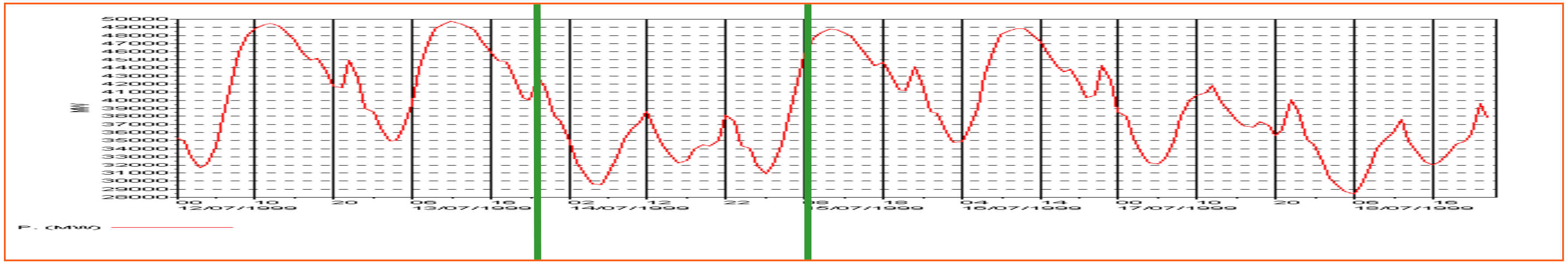
1. Temperature : forecasting errors

12/09/2004 : erroneous forecasting of temperature leads to erroneous forecasting of load



The Demand : Uncertainties ξ_{δ} (Constraint I)

2. Social Events : Bank Holiday, Strike, Football competition, …



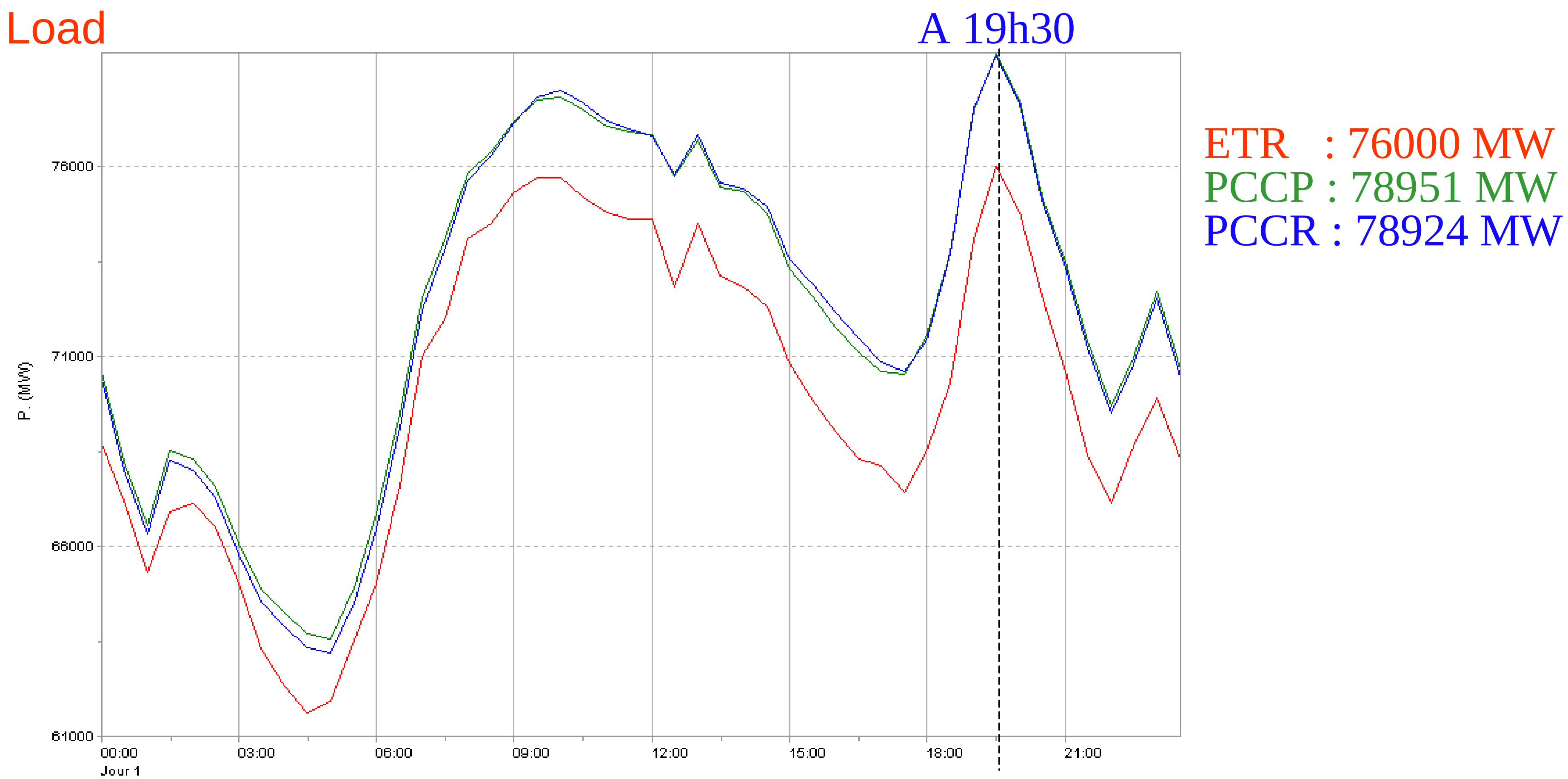
3. Economic Context :

- **Industrial activity**
- **Customers behavior & competition (new customers or loss)**
- **Exchanges with other countries**

The Demand : A Forecast (Constraint I)

Limitation of forecasting : strike (1/2)

Day : thursday 10/03/2005 (good weather forecast, bad demand forecast STRIKE)



The Offer – The Assets (Constraint I)

Physical Assets

θ

59 nuclear power plants

50 classical thermal plants
(coal, fuel, gas)

η

50 hydro valleys

Financial Assets

$\mu, \ \sigma$

Purchases
(markets & producers)

Interruption Options

ϵ

Regulated transactions

- cogeneration
- renewables

The Offer – Thermal Power Plants

Main Characteristics

Costs

$$c = c_d + (c_f + c_p P + c_q P^2)\Delta t$$

$$c_d^{Log} = c_1 + c_2 Ln(\frac{d}{c_3})$$

Constraints

Static constraints

- Limitations on Pmin & Pmax , on spinning reserves
- defined scheduling of production

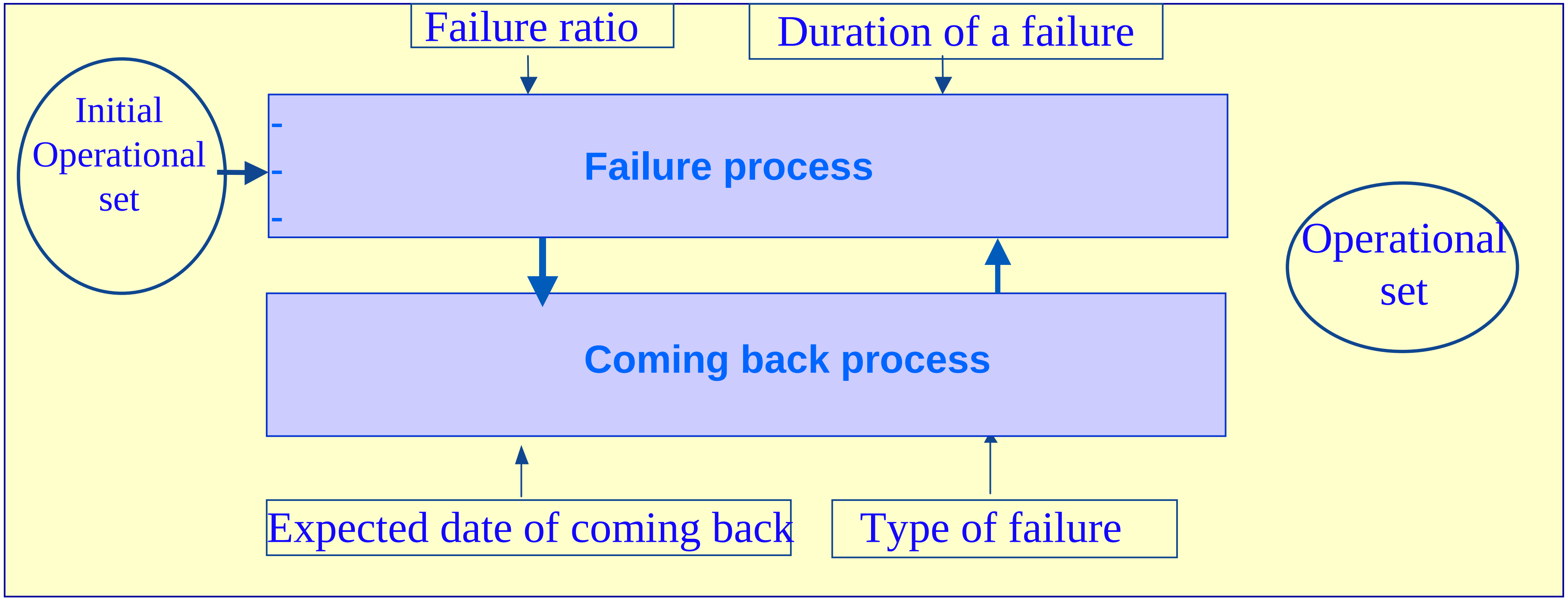
Dynamic constraints

- minimal duration of stop/running/production level
- Starts/stops levels
- Gradients up/down production
- Max number of daily startings, of power modulation per day
- Additional Complex constraints for Nuclear Power Plants

The Offer – Thermal Power Plants

Uncertainty : Availability of the production units

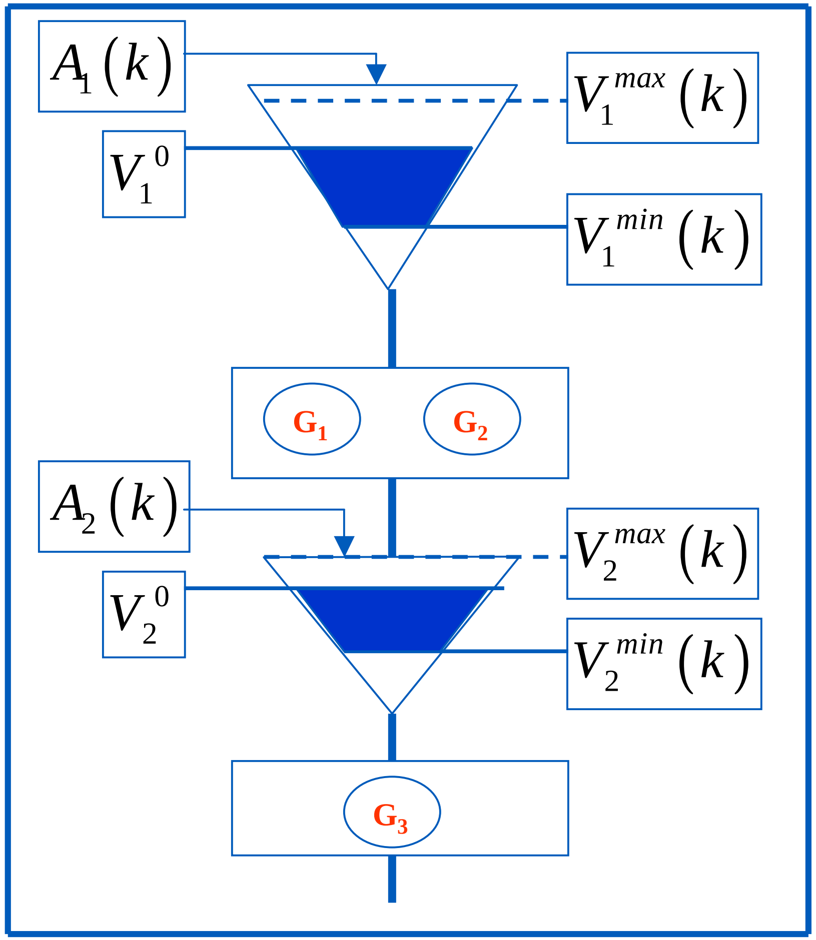
Random outage process



The Offer – Hydro Valleys

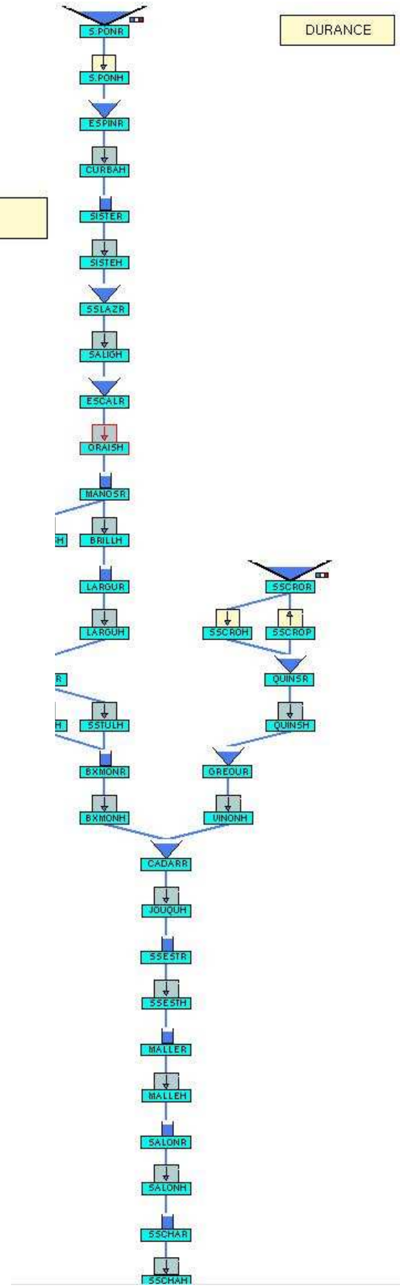
<u>A valley :</u>

a set of interconnected hydro units and reservoirs (> 100 hydro units)

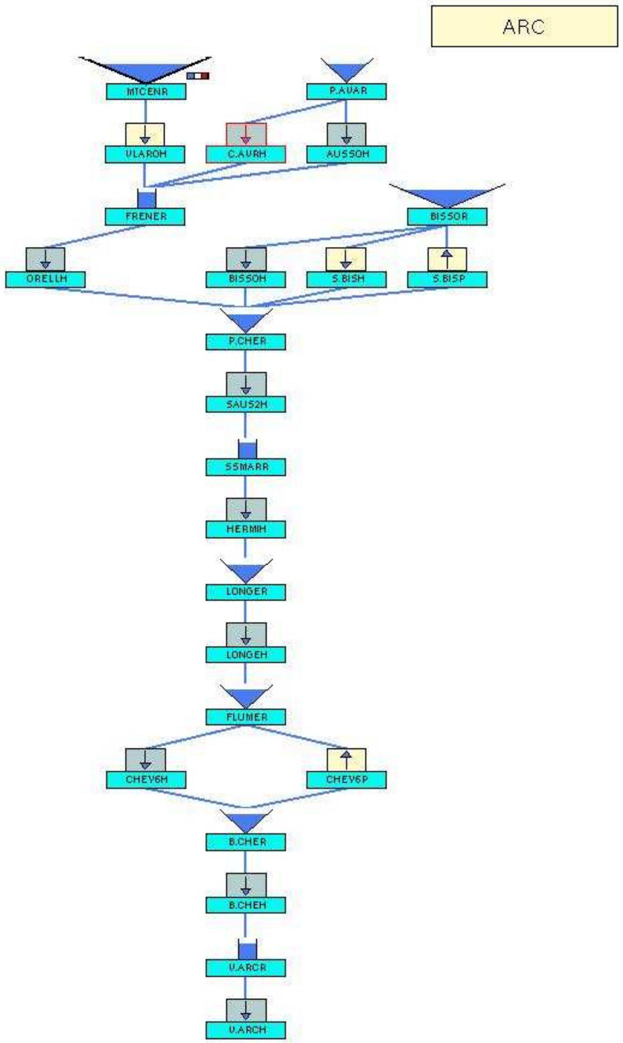


The Offer – Hydro Valleys

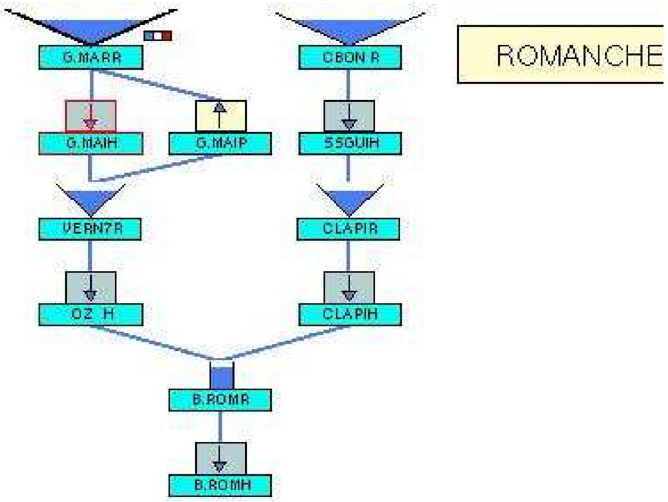
Big size valley



Medium size valley



Small size valley



The Offer – Hydro Valleys

Main Characteristics

Costs $\sum_{r \in V} \omega_r \left(V_r^I - V_r^F \right)$

$\left[\frac{€}{m^3} \right]$

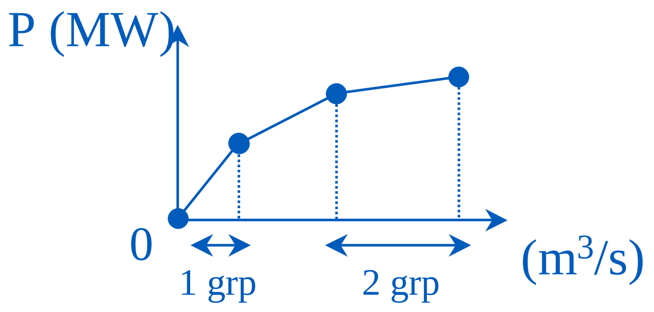
Water-value ω: for taking the future into account (data provided by yearly model).

Constraints

Static constraints

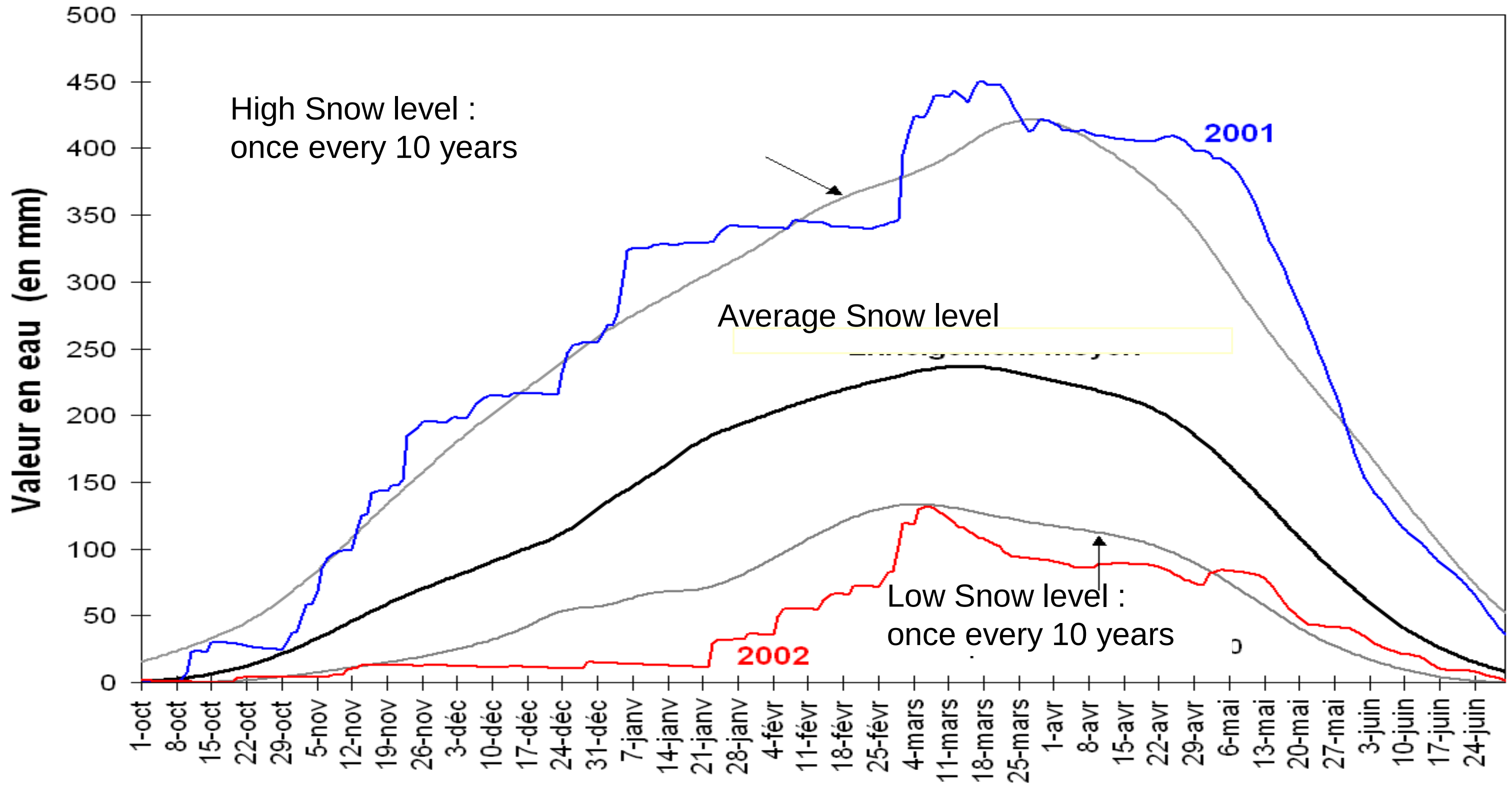
- Boundaries on volumes of reservoirs
- Limitations on hydro-productions
- (power & m3)

Flow/Power curve



The Offer – Hydro Valleys

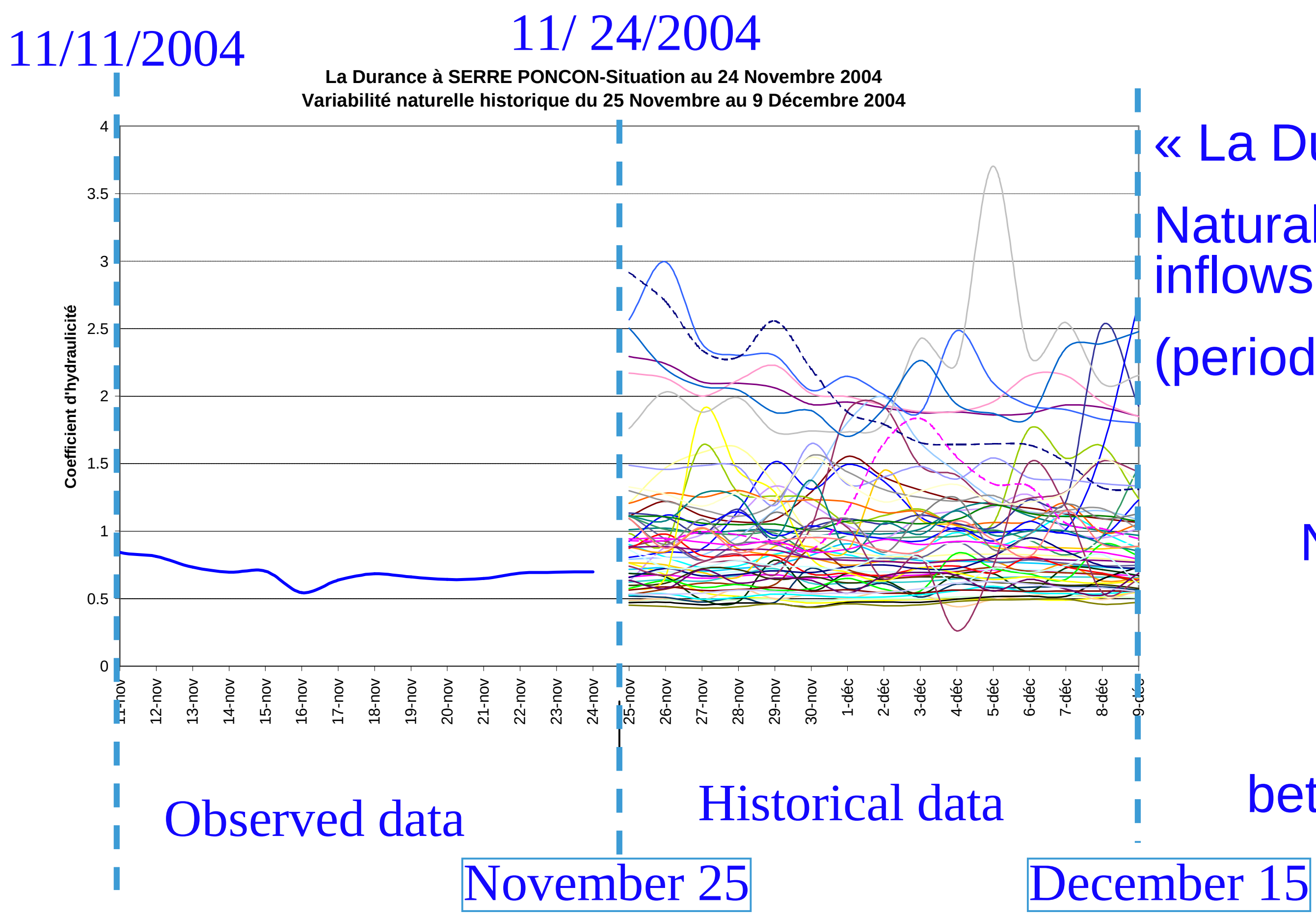
Uncertainty on hydro inflows : High hydro variability due to snow level



La Durance River at Serre-Ponçon (3730 km2) : evolution of snow stock for years 2001-2002 and comparison with historical references (period 1948-2000).

The Offer – Hydro Valleys

Uncertainty on hydro inflows : high natural variability



« La Durance » River :

Natural observed normalized inflows

(period from 11/25 to 12/15)

High variability :

Normalized inflow γ

$$0.3 \leq \gamma \leq 3.7$$

(80% of values between 0.53 and 1.8)

The Offer – Financial Assets

Futures on the Markets

Base/peak

Spot

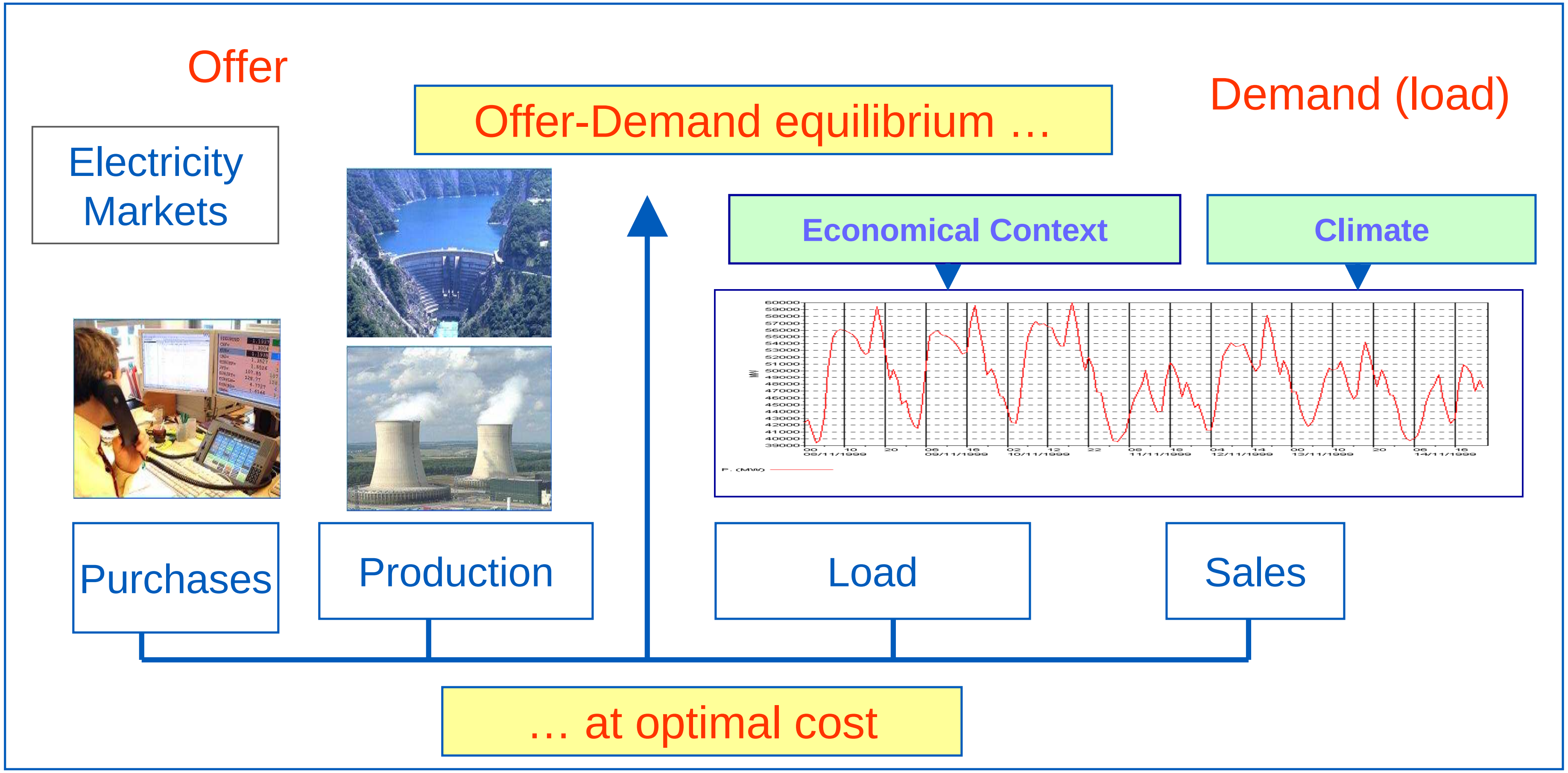
Week Ahead

Week-End Ahead

Interruptions Options contracts

$$n_p \; : Power \; P_p, \;\; cost \; c_p$$

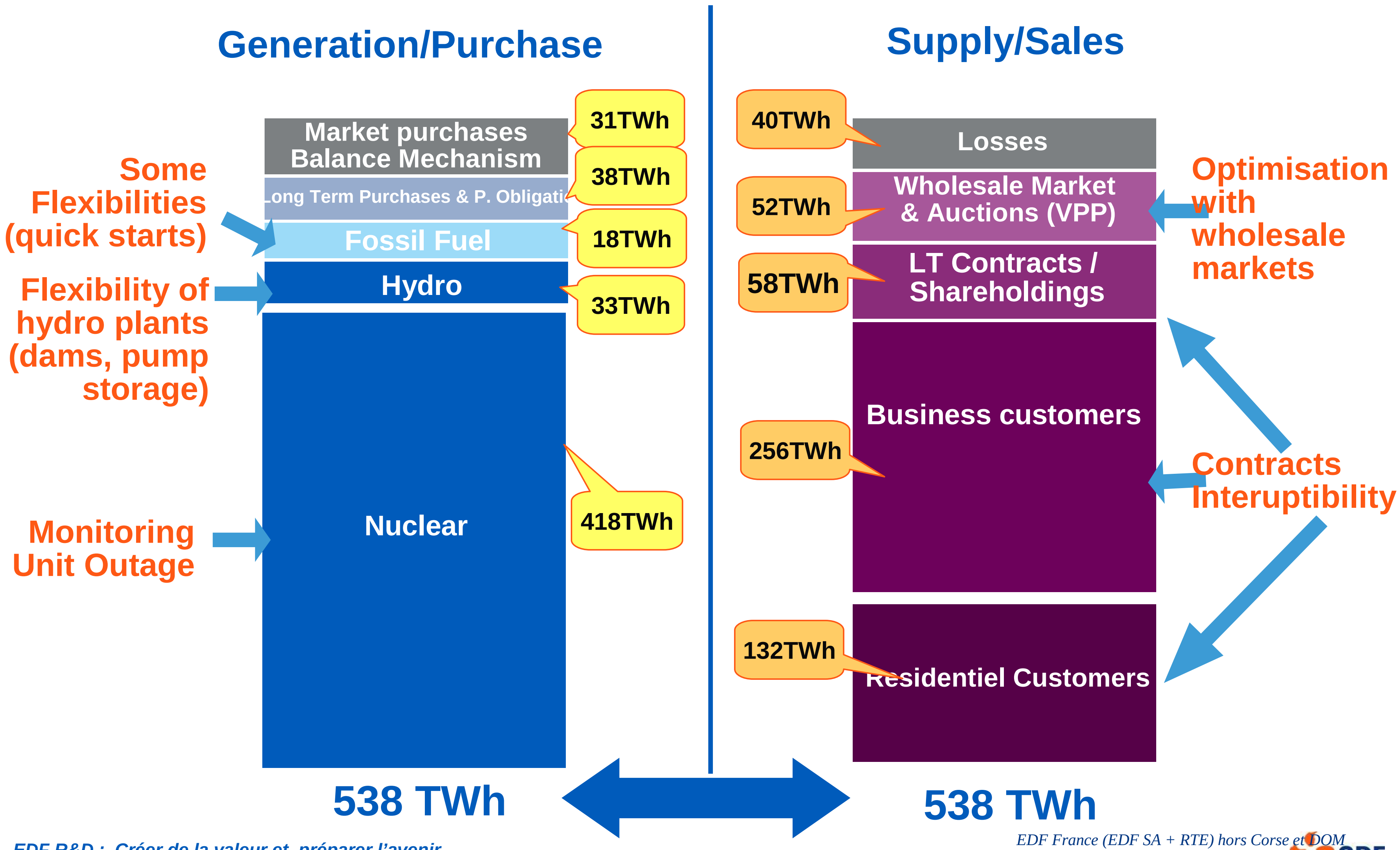
Storing electricity is not economic as of yet !



➡ Key requirement of the Electricity Management

$$O_i^{\Phi}(\xi_{\theta},\xi_{\eta})+O_i^{\Psi}(\xi_{\mu},\xi_{\sigma})\geq D_i(\xi_{\delta})$$

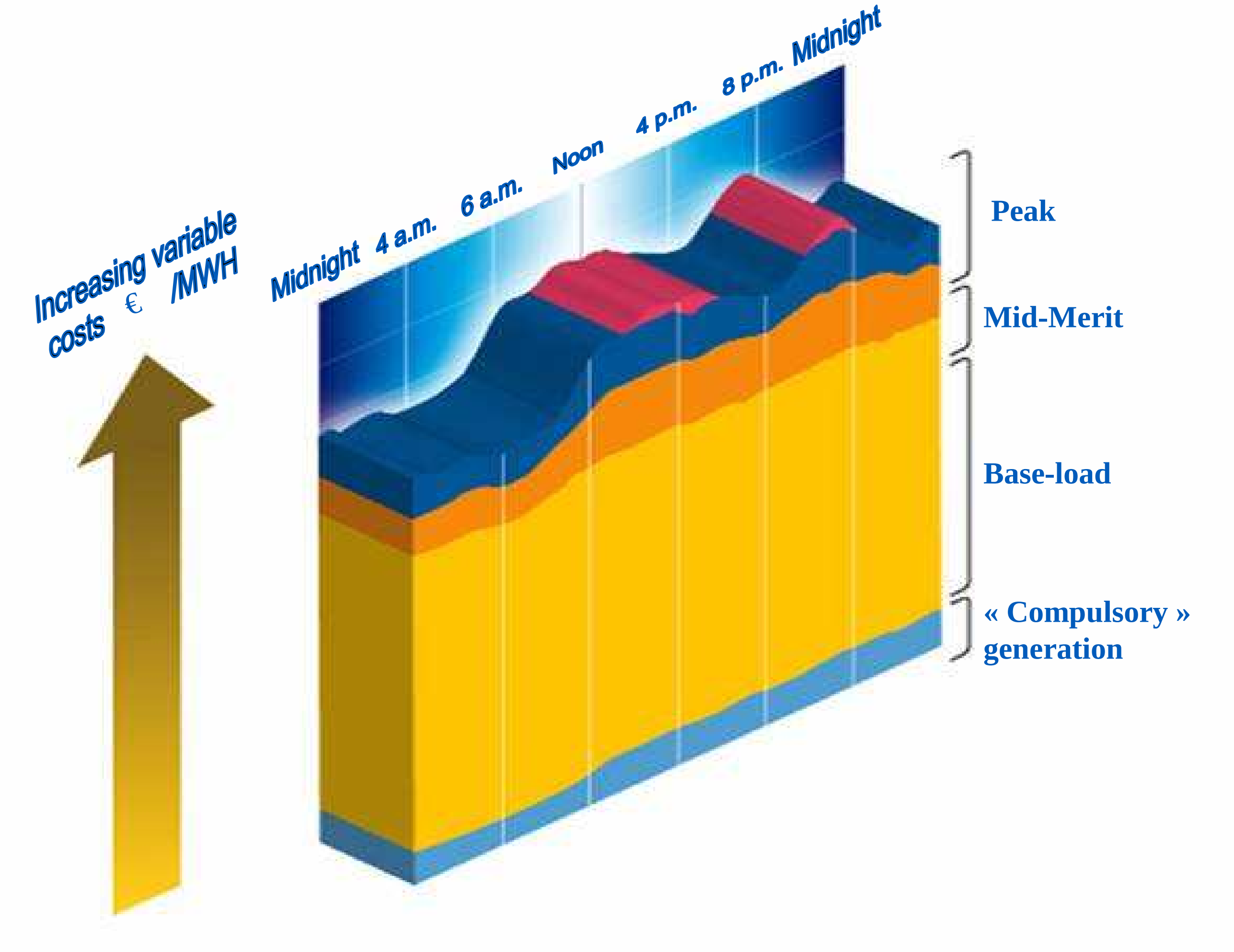
Storing electricity is not economic as of yet !



EDF

Generation using Merit Order (variable costs)

Example of a high consumption on a winter day



- Combustion Turbines
- Hydro (reservoirs)
- Thermal (oil, coal)
- Nuclear
- Hydro (run-of-river), purchase (co-generation, windfarms, …)

2

Some Challenging Features of Energy Management Optimization Problems

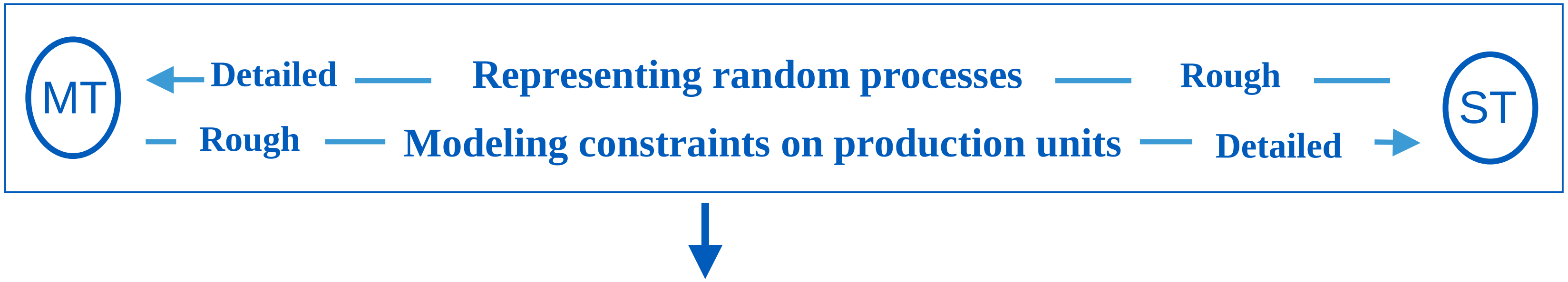
A Generic Optimization Problem for saving € !

Goal : Minimize the global cost of production

Constraints I : Satisfy the offer-demand equilibrium at each time step
Constraints II : Respect

- **the technical contraints of production units (thermal, hydro, renewable)**
- **characteristics of contracts, markets products, delivery, transaction capacities**

(Constraints III : Financial risks)



Economical stakes : fuel costs 3-4 Billion € / year (Nuclear fuel costs 2.4 Billion € / year**)**

- efficient management of nuclear stocks & outages saves 100 Millions € / year
- non-availability of a nuclear power plant during winter week : 1.2 to 1.5 Millions €
- efficient management of reservoirs and hydro production saves 200 to 300 Millions € / year on fossil fuel cost

Challenging Features of Energy Management Optimization Problem

Some challenging key features are :

→ **a) Uncertainty**

b) Binary variables

c) Big size

d) Non-linearity

e) Non-convexity

2a

Some Challenging Problems in Energy Management

a) Dealing with Uncertainty

Uncertainties in generation management

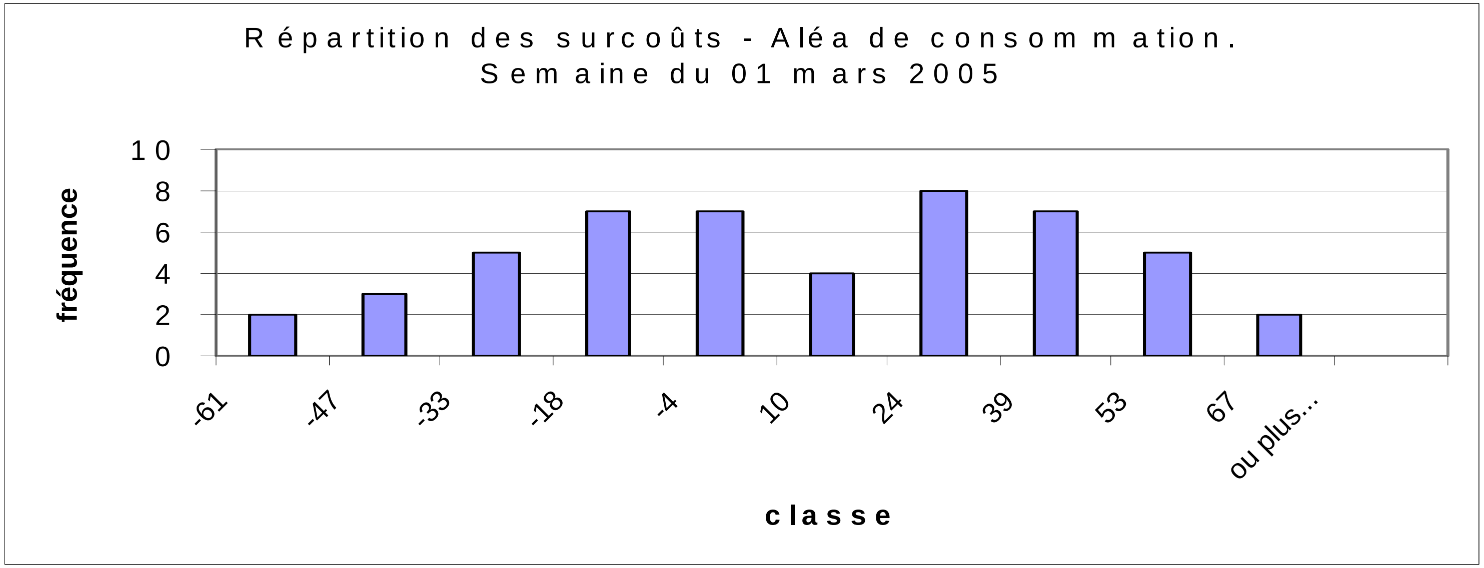
- **Meteorological uncertainties :**
  - **Temperature => impact on demand (1℃ less is ~1400 MW mo re)**
  - **Wind power => wind generation**
  - **Sun**
  - **Natural Inflows to reservoirs**
- **Technical uncertainties**
  - **Plant failures**
  - **Shut-down duration**
  - **Level of fuel stock**
- **Economical uncertainties**
  - **Prices on market, economical context …**

Some of these uncertainties being correlated, especially during extreme phenomenas

Motivation 1 : the risk

EFFECTS OF UNCERTAINTIES ON UNIT COMMITMENT

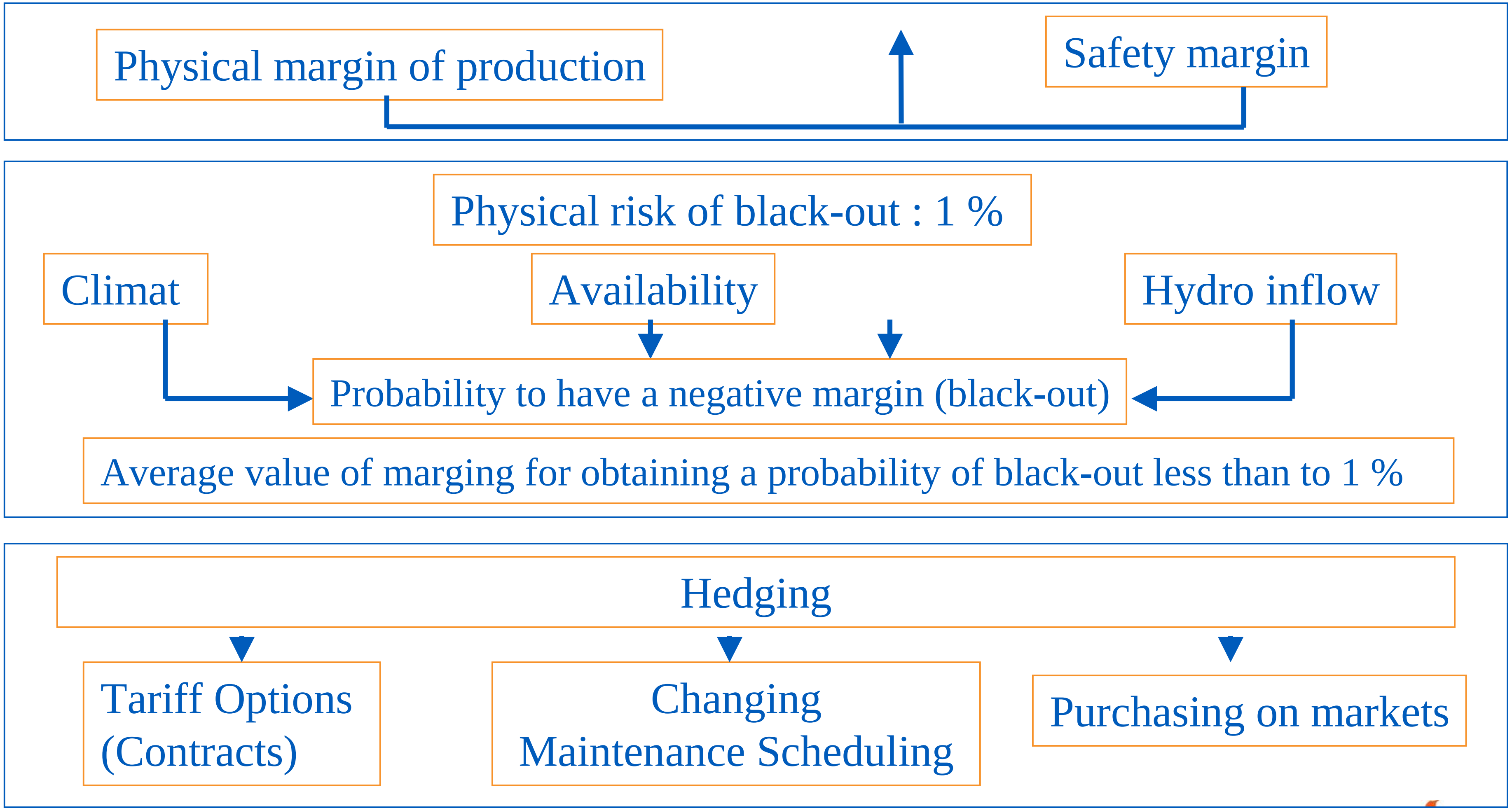
Strong variability on results : → Costs & Risks



Necessity to take uncertainty into account for managing the risk

Motivation 2 : Managing the risk of blackout

Physical & financial risk management & hedging,
saling/purchasing on the electricity markets



Whitch method for taking uncertainty into account ?

Realistic Scenarios → Pseudo stochastic → rough

Uncertainty set → **Robust Optimization**

↓

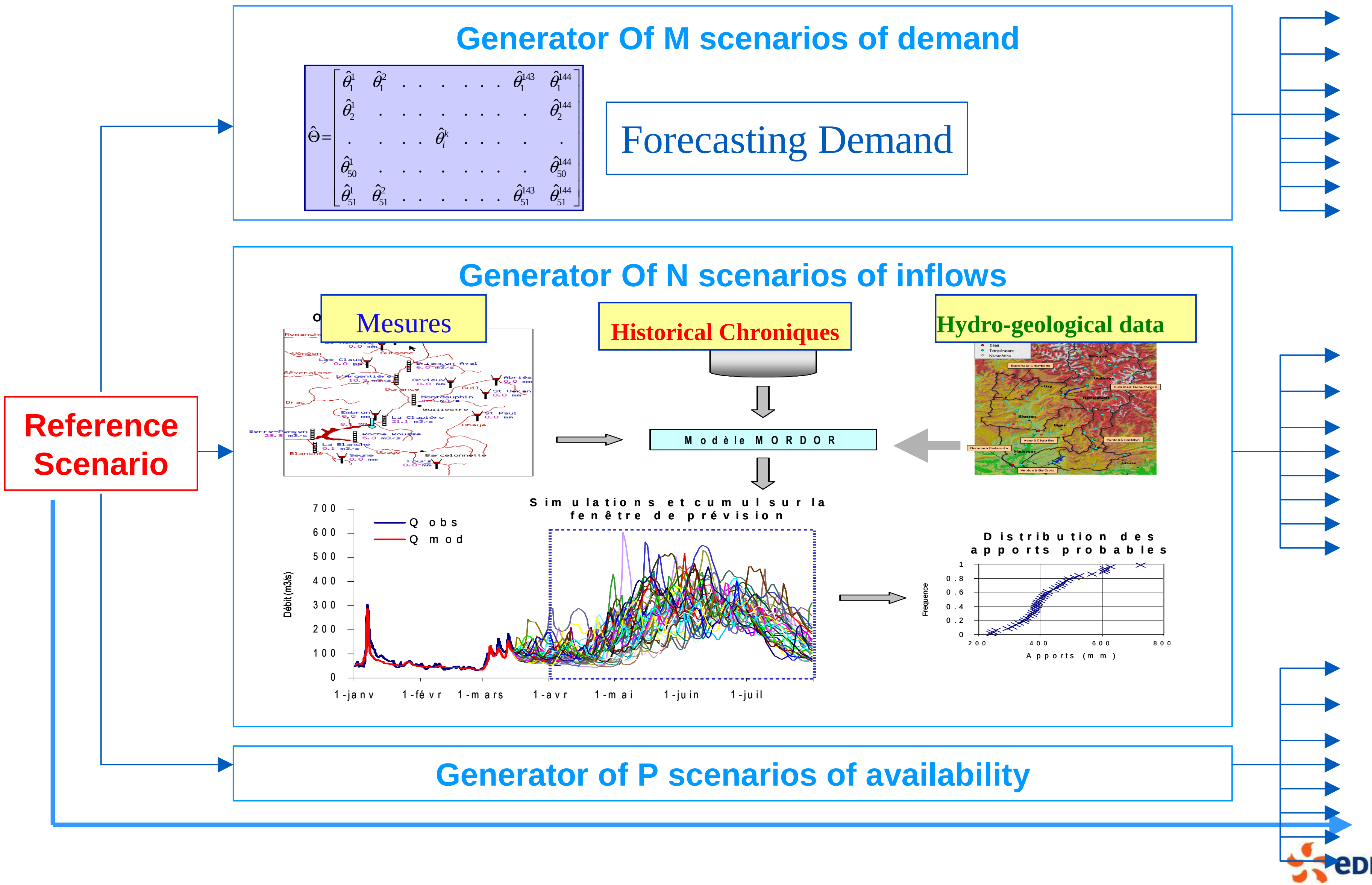
Distributionnally Robust Optimization Tractable ?

↑

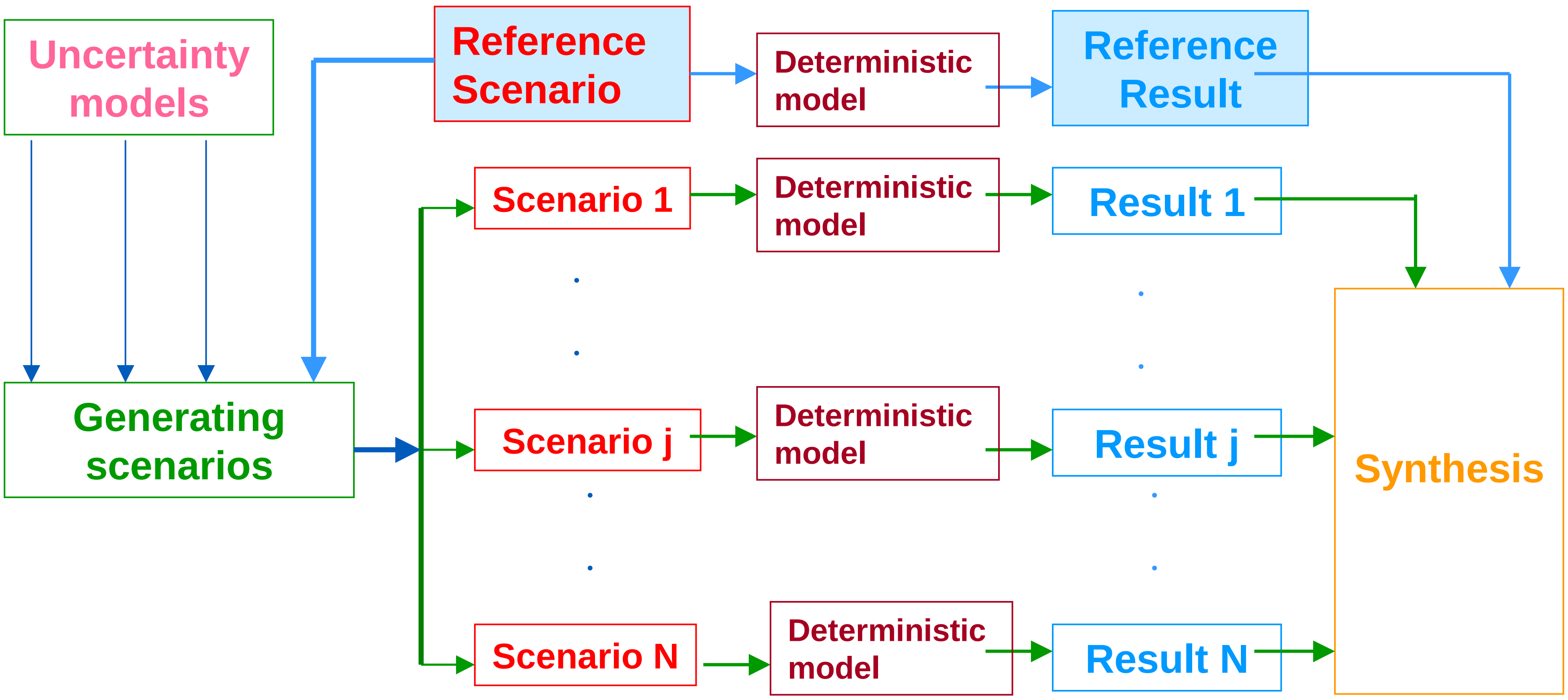
Probability Laws → **Chance Constrained Programming**

Scenario Tree → Stochastic Programming → huge

Can we exploit realistic scenarios ?

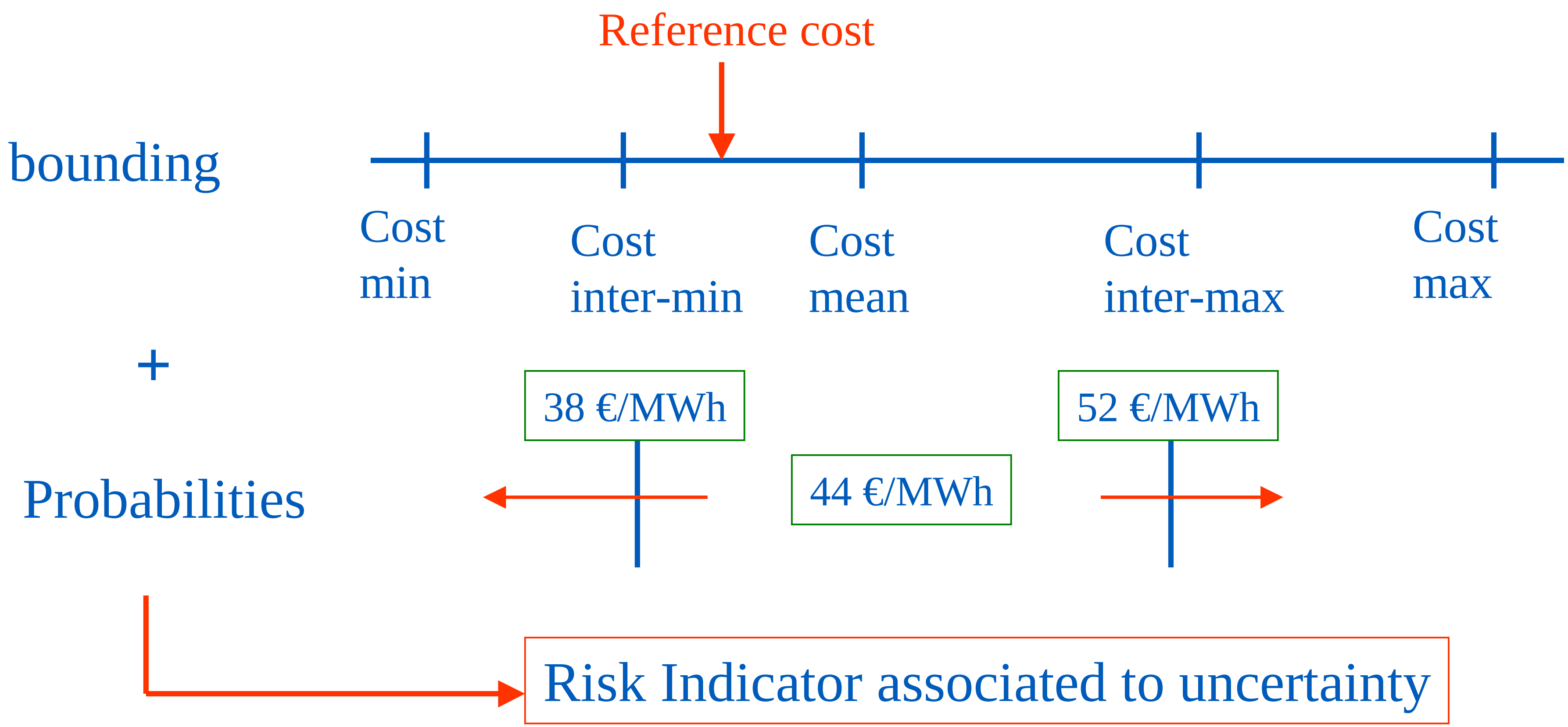


Can we exploit realistic scenarios ?



Can we exploit realistic scenarios ?

Aim : bounding & probabilities, risk, Production cost, marginal cost



Can we exploit realistic scenarios ?

-Do not need the development of a new model

- Needs the development of sophisticated models of uncertainties

- Industrially implementable thanks to high clustering & parallel computing

- rough idea of the effects of uncertainties

- validity ? No rigorous

Key question : can we integrate complex realistic models of uncertainty in rigorous optimization process ?

Part II :

Some Challenging Problems

3

At Mid-Term

3a

At Mid-Term :

Uncertainty on Equilibrium Generation/demand

Experiment around Chance Constrained Programming

Balance between generation and demand

General Probabilistic Model (1/2)

$$\begin{aligned}\min \quad & f[c(x,\xi)] \\ s.t. \quad & \mathbb{P}[A(\xi)x \geq b(\xi)] \geq 1-p \\ & \mathbb{P}[h^{min}(\xi^\eta) \leq Hx^\eta \leq h^{max}(\xi^\eta)] \geq 1-q \\ & Px \leq h \\ & x \in X\end{aligned}$$

$$x = (\; x_\theta \quad x_\eta \quad x_\mu \quad x_\sigma \quad x_\epsilon)^T \qquad \xi = \Xi(\xi_\theta, \xi_\eta, \xi_\mu, \xi_\sigma, \xi_\delta \quad \xi_\epsilon)$$

↓

$$x_\theta = (\; x_\theta^{nuc} \quad x_\theta^{coal} \quad x_\theta^{gas} \quad x_\theta^{fuel})$$

Balance between generation and demand

General Probabilistic Model (2/2)

assets $j = 1, \ldots, n$

$$A(\xi) = \begin{pmatrix} A^{\theta}(\xi_{\theta}) & A^{\eta}(\xi_{\eta}) & A^{\mu}(\xi_{\mu}) & A^{\sigma}(\xi_{\sigma}) & A^{\epsilon}(\xi_{\epsilon}) \end{pmatrix}$$

time $i = 1, \ldots, m$

$$A^{\alpha}(\xi_{\alpha}) = \begin{pmatrix} a^{\alpha}_{11} & \ldots & a^{\alpha}_{1N^{\alpha}} & \ldots & 0 & \ldots & 0 & \ldots & 0 & \ldots & 0 \\ & & & \ddots & & & & \ddots & & & \\ 0 & \ldots & 0 & \ldots & a^{\alpha}_{i1} & \ldots & a^{\alpha}_{iN^{\alpha}} & \ldots & 0 & \ldots & 0 \\ & & & \ddots & & & & \ddots & & & \\ 0 & \ldots & 0 & \ldots & 0 & \ldots & 0 & \ldots & a^{\alpha}_{m1} & \ldots & a^{\alpha}_{mN^{\alpha}} \end{pmatrix}$$

Balance between generation and demand

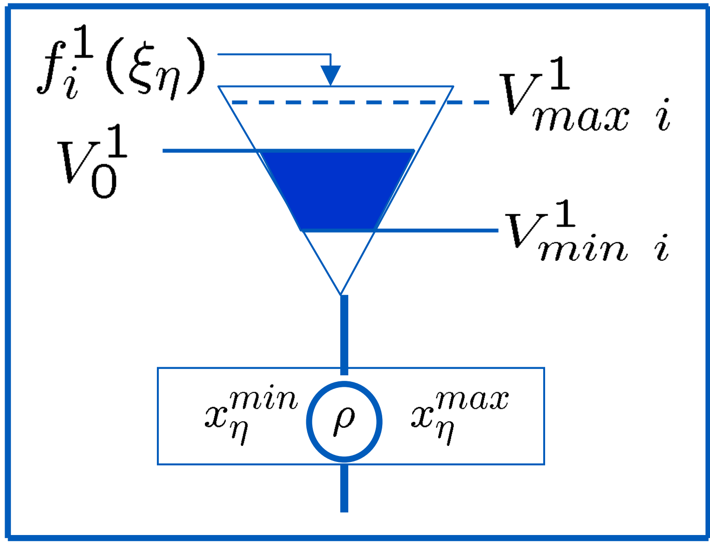
Simplification : individualization of chance constraints (1/4)

$$\begin{aligned} \min_x \quad & c^t x \\ s.t. \quad & \mathbb{P}[\langle A_i(\xi^\theta), x\rangle \geq b_i(\xi^\delta)] \geq \alpha_i, \ \forall i \\ & \mathbb{P}[\langle H_i, x^\eta\rangle \leq h_i^{min}(\xi^\eta)] \geq \beta_i, \ \forall i \\ & \mathbb{P}[\langle H_i, x^\eta\rangle \geq h_i^{max}(\xi^\eta)] \geq \beta_i, \ \forall i \\ & \langle P_i, x\rangle \leq h_i, \ i = 1, ..., m \\ & x \geq 0 \end{aligned}$$

$$h_i^{min}(\xi^\eta) = v_0 + \sum_{i0=1}^{i} f_{i0}(\xi^\eta) - v_i^{min}$$

$$h_i^{max}(\xi^\eta) = v_0 + \sum_{i0=1}^{i} f_{i0}(\xi^\eta) - v_i^{max}$$

$$H_{ij} = \mathbb{1}_{j \leq i}$$



Balance between generation and demand

Simplification : available information (2/4)

historical data

$$a_{ij}(\xi_\alpha) \in [a_{ij}(\xi_\alpha)_{min}, \; a_{ij}(\xi_\alpha)_{max}]$$
$$b_i(\xi_\delta) \in [b_i(\xi_\delta)_{min}, \; b_i(\xi_\delta)_{max}]$$

Exploiting minimal information on random processes :

$$a_{ij}(\xi)_{min}, \; a_{ij}(\xi)_{mean}, \; a_{ij}(\xi)_{max}$$

Hypothesis : Independence of $a_{ij}(\xi_\alpha), \; b_i(\xi_\delta)$

Hoeffding Theorem → individual chance constraint → SOCP

Balance between generation and demand

Simplification : Convex Approximation (3/4)

Lemma 1 : *Any Individual Chance Constraint*

$$\mathbb{P}[\langle A_i(\xi), x\rangle \geq b_i(\xi_\delta)] \geq \alpha_i, \ \forall i \in I$$

is approximated by the 2 (convex) conic quadratic inequalities :

$$\langle \mathbb{E}[A_i(\xi)], x)\rangle - \sqrt{(1/2)|\ln(1-\alpha_i)|}\, \|\Delta_i x + \delta_{bi}\|_2 \ \geq \ \mathbb{E}(b_i)$$

$$\langle \mathbb{E}[A_i(\xi)], x)\rangle \ \geq \ \mathbb{E}(b_i)$$

$$\delta_{b_i} = (b_i^{max} - b_i^{min})$$

$$\Delta_j = \begin{pmatrix} a_{1j}^{max} - a_{1j}^{min} & \cdots & 0 \\ \vdots & a_{ij}^{max} - a_{ij}^{min} & \vdots \\ 0 & \cdots & a_{mj}^{max} - a_{mj}^{min} \end{pmatrix}$$

Proof : Based on Hoeffding's Theorem : for independent and bounded random variables $X_1, ..., X_m$, noting $S = \sum_{i=1}^m X_i$, the individual chance constraint is bounded as follows:

$$\forall \tau \geq 0, \ \mathbb{P}\left[S \geq \mathbb{E}[S] + \tau\right] \leq \exp\left(\frac{-2\tau^2}{\sum_{i=1}^m (\overline{X}_{ij} - \underline{X}_{ij})^2}\right).$$

□

Balance between generation and demand

Simplification : Computing the solution = solve a SOCP (4/4)

Individual Chance-Constrained Program with Hoeffding bound

↓

$$\begin{aligned} \min_x \quad & c^t x \\ s.t. \quad & \left\| \tilde{A}_l x + \tilde{b}_l \right\|_2 \leq \tilde{f}_{l^t} x + \tilde{d}_l, l \in (1, L) \end{aligned}$$

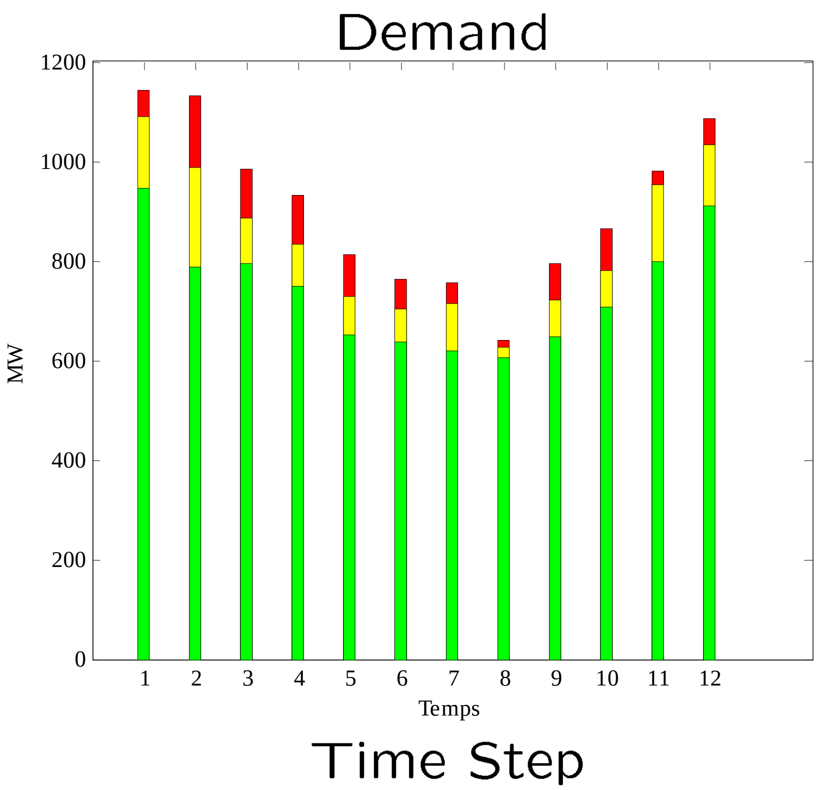
SOCP : Second Order Conic Program

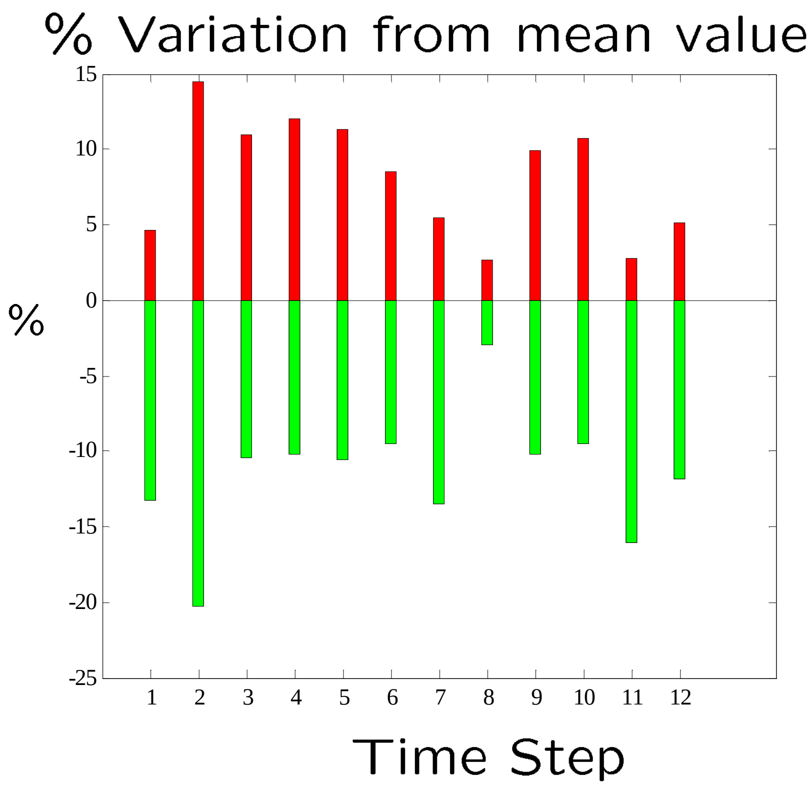
Resolution (polynomial complexity) : Interior Points Method

Balance between generation and demand

Toy Problem 1

Numerical example – Data : The demand



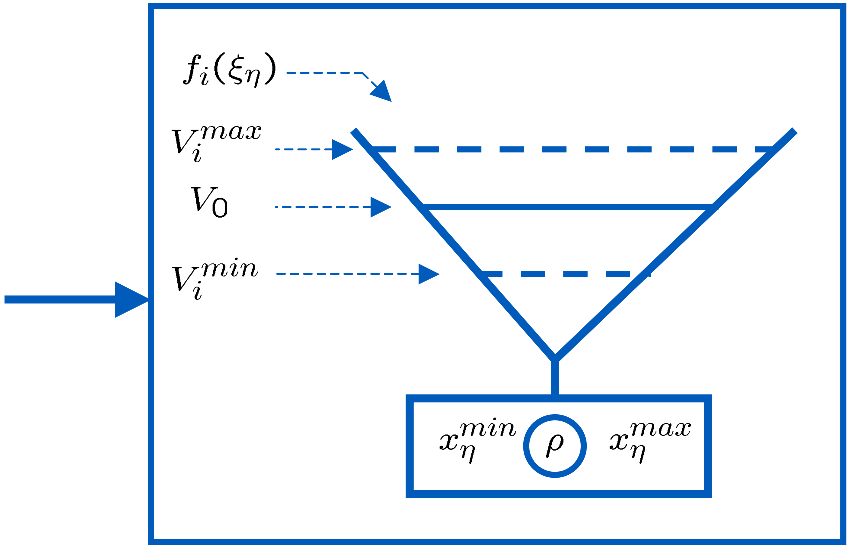


	1	2	3	4	5	6	7	8	9	10	11	12
% max	4.7	14.5	11	12	11.3	8.5	5.5	2.7	9.9	10.7	2.8	5.1
% min	13.3	20.2	10.4	10.2	10.6	9.5	13.5	3	10.2	9.5	16	11.8

Balance between generation and demand

Toy Problem 1 **Numerical example – Data : the Production Units**

- 1 nuclear 900 MW : c1= 30 €/MWh
- 1 coal 650 MW : c2=45 €/MWh
- 1 fuel 250 MW : c3=53 €/MWh
- 1 gas 100 MW : c4=58 €/MWh
- 1 reservoir + turbine : c5=48 €/MWh



Confidence Levels :

For Offer-Demand Equilibrium : 0.95-0.93

For Exploitation levels of hydro reservoir : 0.95

Balance between generation and demand

Toy Problem 1 **Numerical example – Data : Availability coefficients**

nuclear

i	min	mean	max
1	0.79	0.86	0.90
2	0.82	0.87	0.90
3	0.82	0.85	0.89
4	0.74	0.76	0.78
5	0.77	0.79	0.77
6	0.56	0.58	0.66
7	0.57	0.59	0.64
8	0.53	0.56	0.58
9	0.63	0.64	0.67
10	0.74	0.79	0.89
11	0.82	0.84	0.91
12	0.79	0.85	0.95

coal

i	min	mean	max
1	0.77	0.79	0.84
2	0.74	0.78	0.83
3	0.68	0.72	0.75
4	0.64	0.66	0.69
5	0.57	0.59	0.66
6	0.52	0.55	0.58
7	0.56	0.57	0.58
8	0.47	0.49	0.54
9	0.63	0.68	0.71
10	0.69	0.73	0.75
11	0.75	0.78	0.82
12	0.75	0.79	0.84

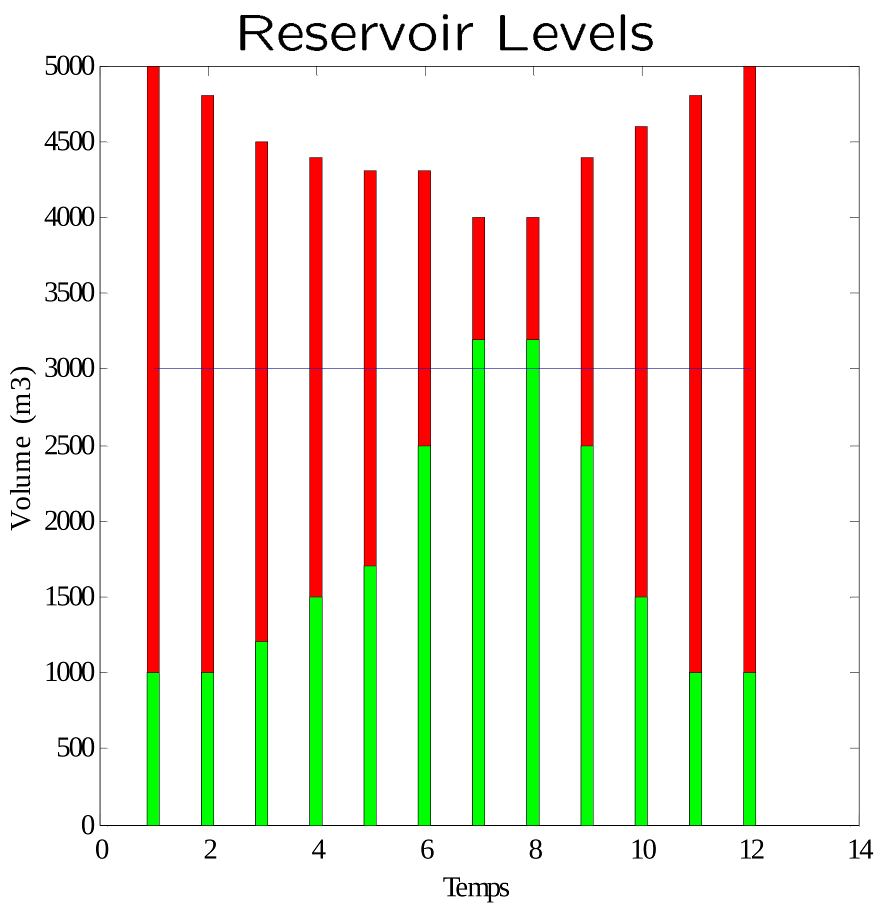
Maintenance of production units : in summer

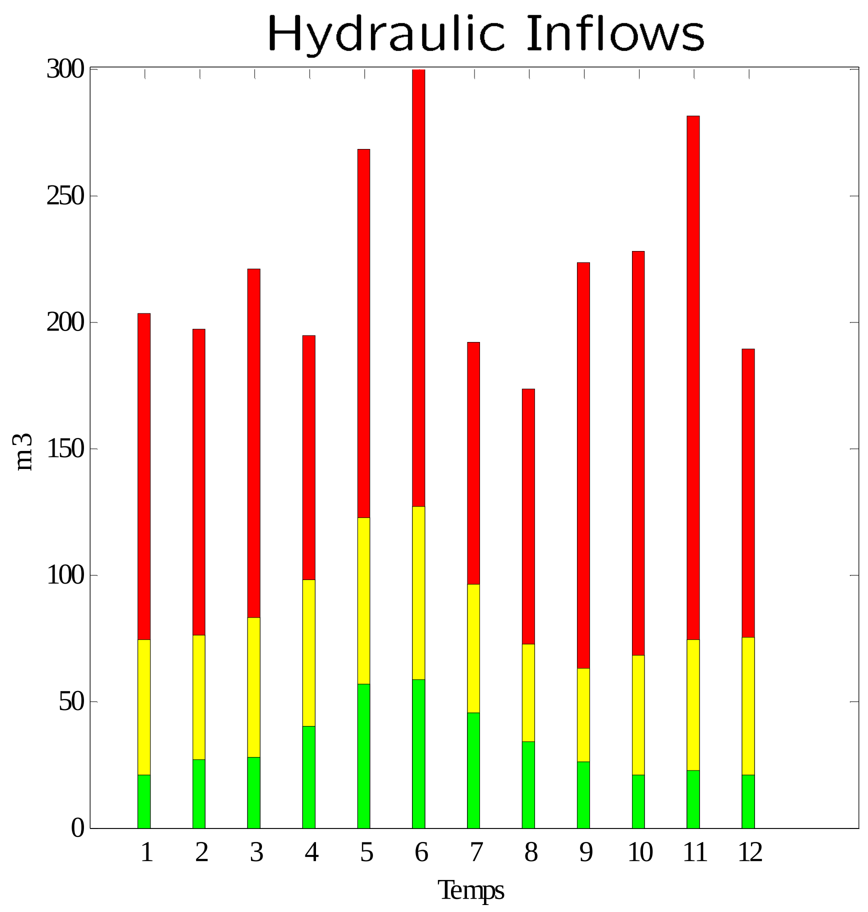
1	2	3	4	5	6	7	8	9	10	11	12
4.7	14.5	11	12	11.3	8.5	5.5	2.7	9.9	10.7	2.8	5.1

Balance between generation and demand

Toy Problem 1

Numerical example – Data : Hydro system





Summer : Touristic Policy

High Variability

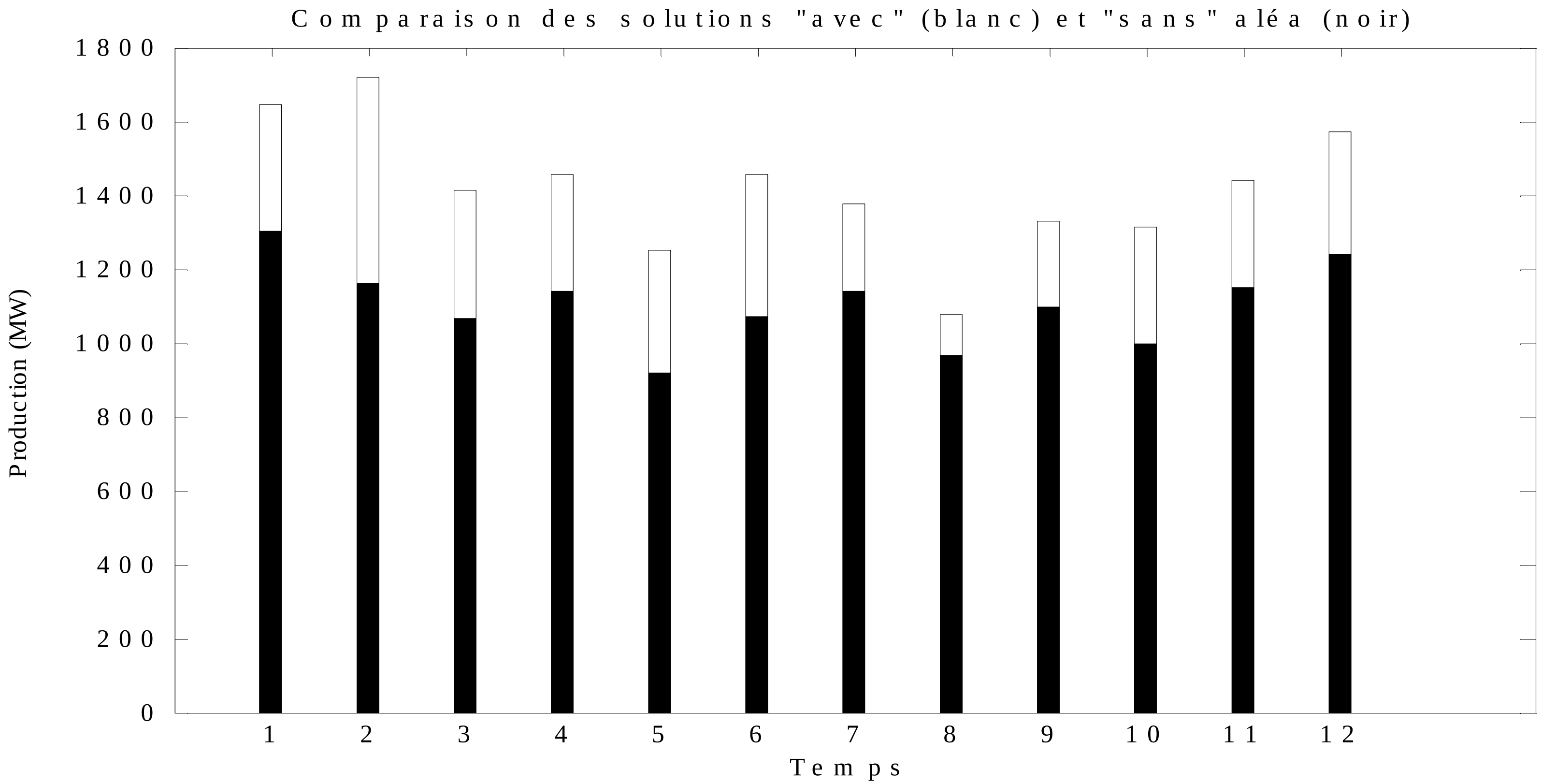
Balance between generation and demand

Toy Problem 1

Numerical example – Results

Cost with Deterministic Policy : 472265

Cost with Stochastic Policy : 649336



Assessment : Chance Constrained Programming

Convexity

Joint One sided (offer-demand)

Joint Bi-sided (bounds of reservoirs)

Convex Bounds of Probability

COOPERATIONS on Exact methods :

René Henrion, WIAS, Berlin
Michel Minoux, LIP6, University Pierre & Marie Curie, Paris

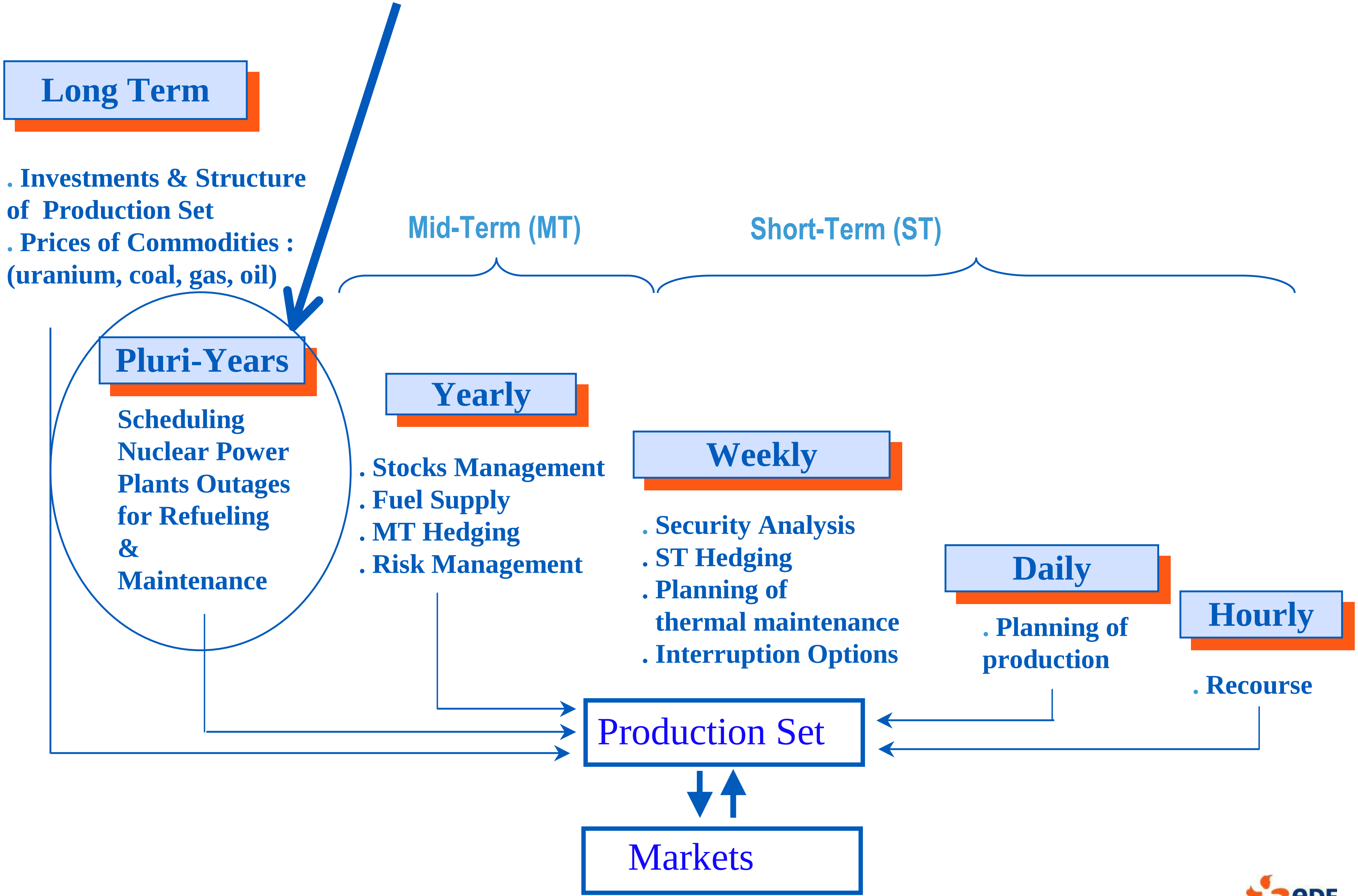
Own EDF research program : Bounds of probability

3b

The Mid-Term :

The Nuclear Outages Scheduling Problem

The Nuclear Outages Scheduling Problem



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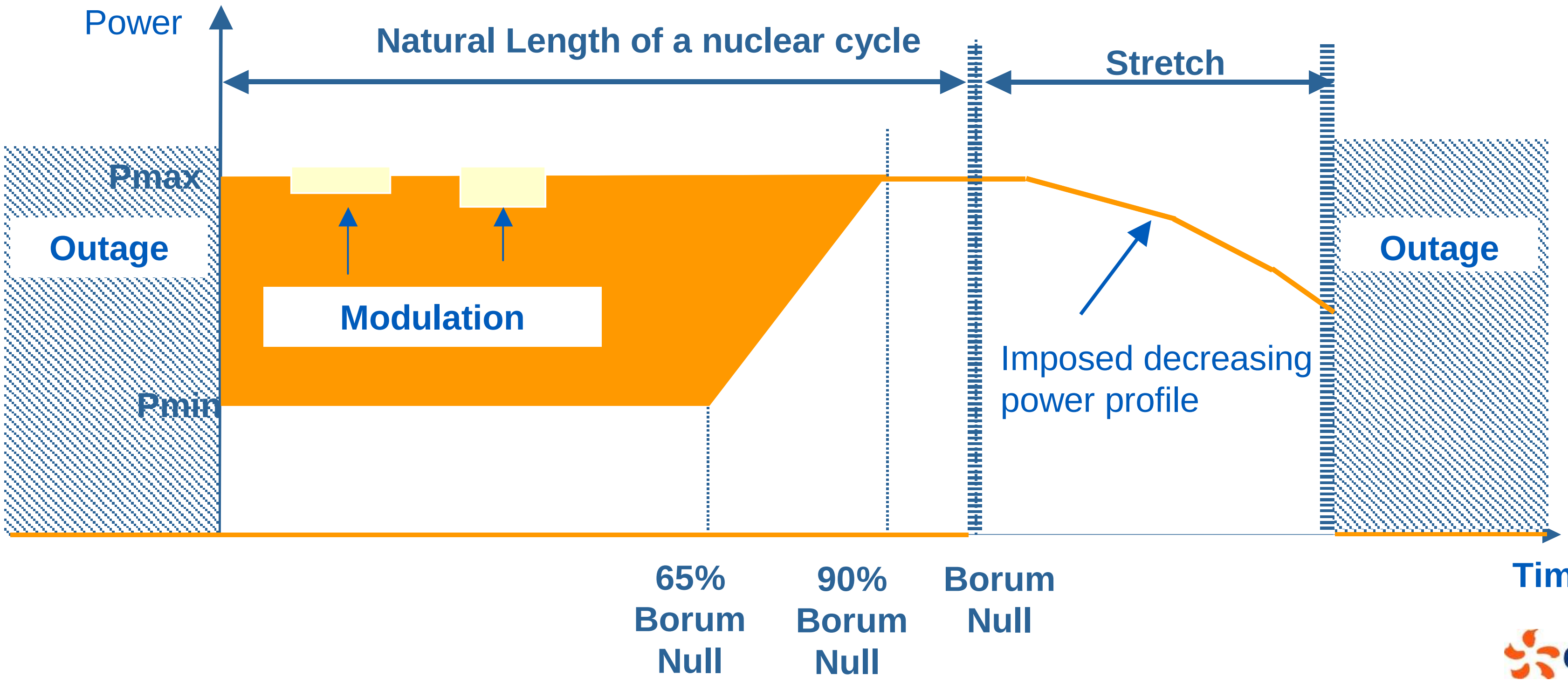
The Nuclear Outages Scheduling Problem

- 58 nuclear power plants on 19 sites
- Nuclear production is about 88% of total production of electricity in France
- The cheapest production after hydro one
- Each 12 to 18 months, nuclear power plants must be stopped for refuelling and maintenance
  - Very expensive operation with huge economical stakes :
    - cost of an outage may vary considerably according to its scheduling : during winter, an outage may cost twice as much as the same outage during summer.
    - the scheduling of outages has a huge impact on the risk of blackout

The Nuclear Outages Scheduling Problem

Nuclear Power Plants : specific Complex constraints

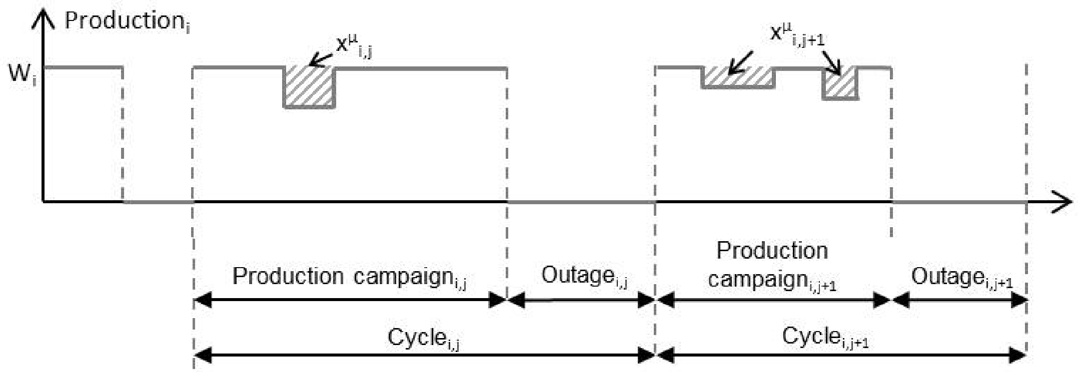
- Production & Modulation
  - The state of nuclear heart is characterized by the concentration in borum
  - Bounds of production Pmin, Pmax are defined by a level of stock of nuclear fuel
  - Modulation : difference between nuclear availability and nuclear production. Used to adapt production to demand or for saving nuclear fuel

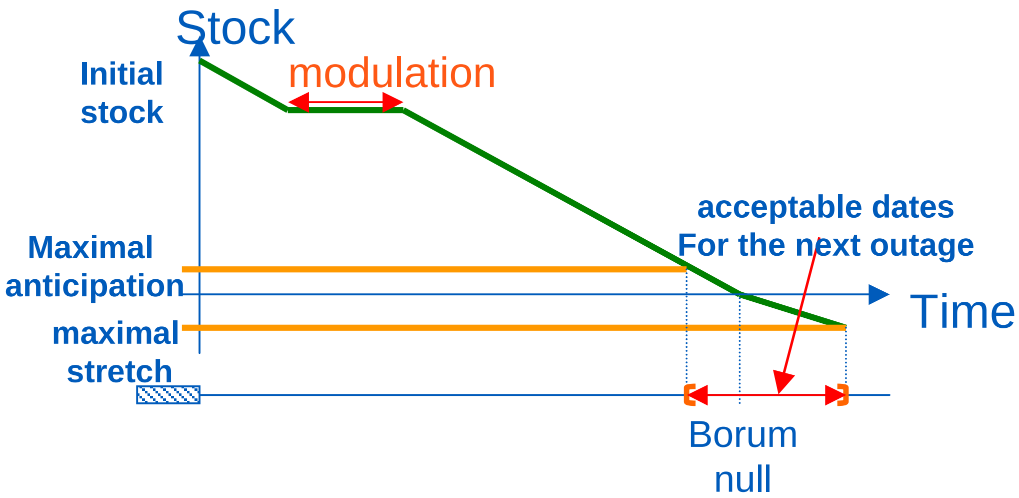


The Nuclear Outages Scheduling Problem

Nuclear Power Plants : specific Complex constraints

- Cycle of the Operation Life of a Nuclear Power Plant





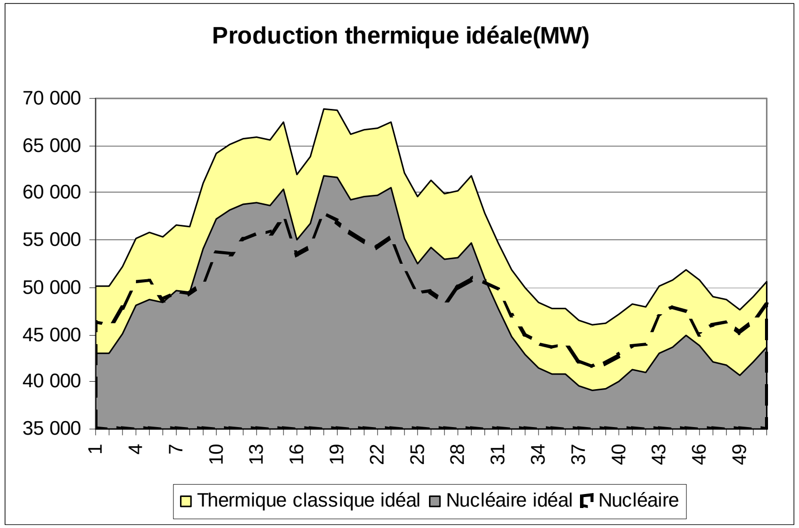
For a given initial stock, there is only 2 ways for modifying the length of the cycle :

- Modulation (limited for a cycle)
- stretch/anticipation (limited too)

The Nuclear Outages Scheduling Problem

The main goal

Compute optimal outages schedules of nuclear power plants which minimize costs and respect operational constraints and seasonnality of the electricity demand



- **Maximal availability in winter**

- **Reasonable availability in summer (cooling)**

- **Avoid significant variations of nuclear availability for limiting to use classical production units of higher costs (coal, gas, fuel)**

Remark : normally, we should optimize with all the park → untractable

→ Nuclear production and classical thermal production are separated

The Nuclear Outages Scheduling Problem

Features of the problem

Minimizing global cost : intrinsic cost of refuelling and replacing cost (the production of the stopped plant has to be replaced by coal of fuel plants at a higher cost)

Decision variables : Outages dates → integer variables

- Amount of nuclear fuel at each refuelling
- production planning of each plant

Constraints :

- **Satisfy the demand** (coupling constraint)
- **Technical constraints** : power level at end of cycle, min/max power, min/max levels on fuel stock,…
- **Outages constraints** : limited human and machines resources available (some resources required for maintenance and reloading operations are shared among the plants) : max number of outages at the same time, early/late dates for some outages,…

Many uncertainties : Demand, prices, availability of plants (due to random failures), amount of nuclear fuel left, duration of outages

Strongly combinatorial, stochastic and nonlinear optimization problem of big size :

between 3 and 5 outages to plan for each plant, over a 5 years period; a weekly time step

10000 integer variables, 100000 real variables, 1.7M constraints (deterministic approach)

Assessment : An unsolved problem

COOPERATIONS :

Challenge ROADEF :
international teams proposed approaches based on heuristics

Agnes Gorge (PhD student) under supervision of Abdel Lisser, University Paris-Sud Orsay :
- **combinatorial feature : SDP relaxations & cuts**
- **uncertainty : distributionally robust**

Nicolas Dupin (PhD student)
- **modeling : linearizing → towards a huge PL of**
- **big size : column generation**
- **uncertainty : approach ?**

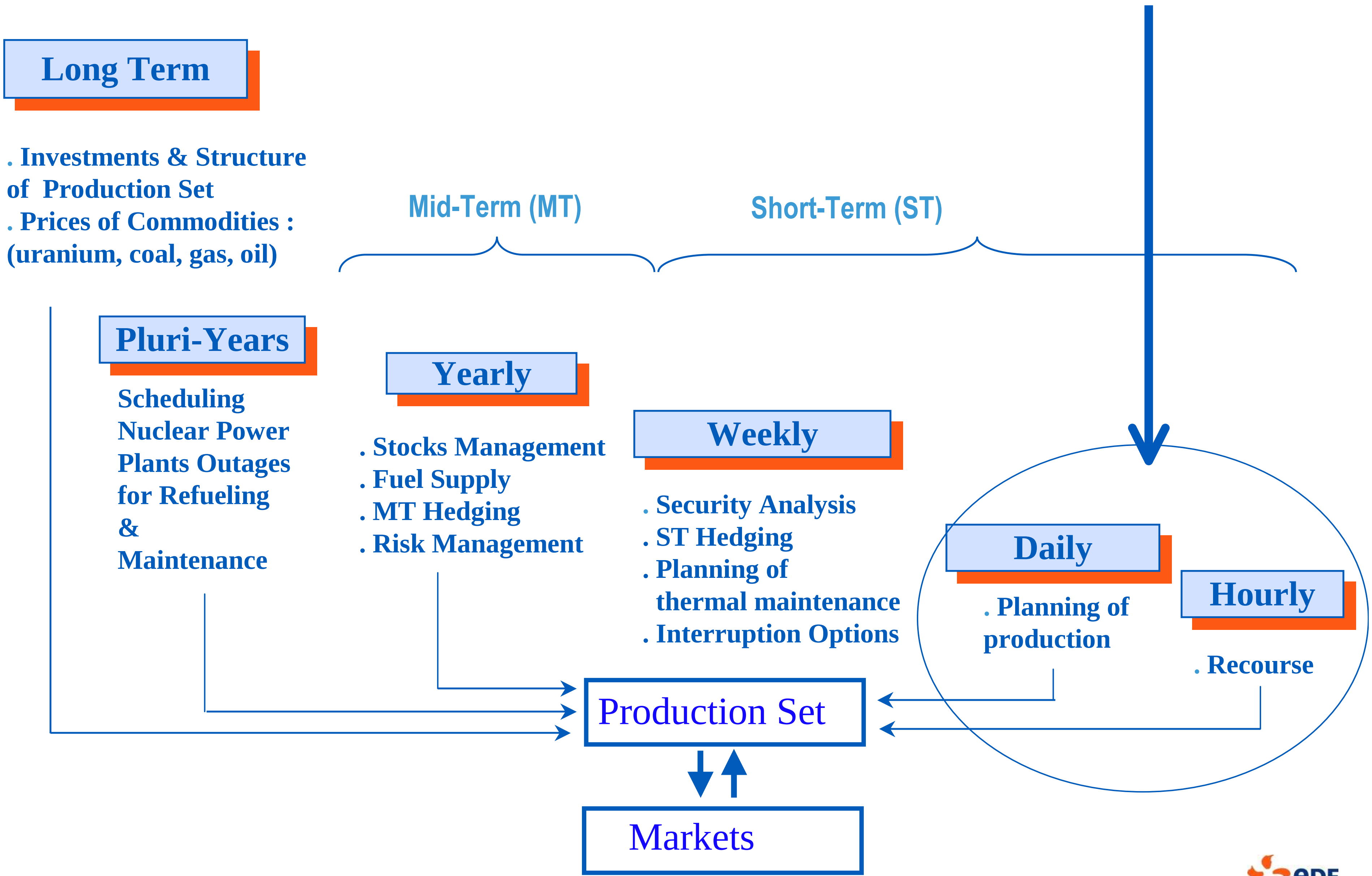
Own EDF research program : Modeling; Approximate solutions, heuristics

4

At Short-Term :

The Daily & Intra-Daily Unit Commitment Problem

The Daily & Intra-Daily Unit Commitment Problem



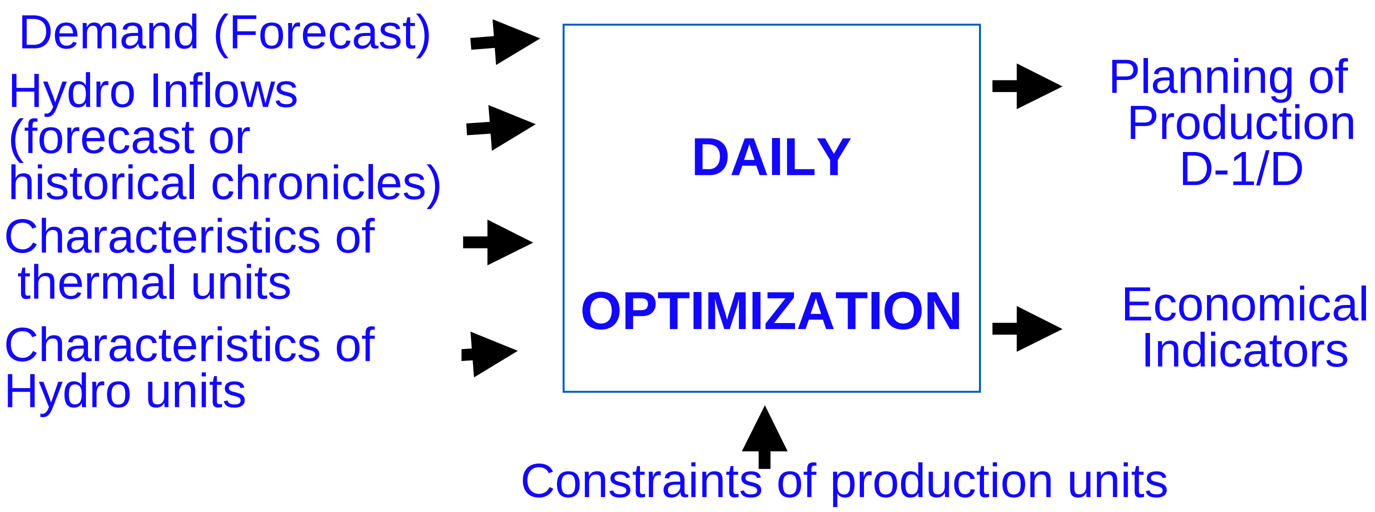
The Daily Process

	Forecasting temperature (meteorological service)
07:00 – 08:00	**Collecting & Processing data needed by the optimization model** - forecasting the demand - forecasting the hydraulic inflows - forecasting the markets prices
08:00 – 09:30	**Starting the optimization process** - Thermal & Hydrau : 12 minutes - when adding markets & Tariffs options : 30 minutes - when adding the spinning reserves option : 60 minutes
09:30 – 10:00	**Analysing the results**

The Daily Optimization

The main goal

Compute, today for tomorrow, the production planning of each plant (nuclear, coal, fuel, gas, hydro) which minimize the global cost of production and respect all technical constraints of production units while satisfying the electricity demand



Very strong requirements

- on optimality (gap of 1% = several millions of euros per year)
- on feasibility (all schedules have to be technically feasible)
- a problem to solve in less than 10 min due to the constraints on the operational process

The Daily Optimization

Features of the problem

Minimizing global cost : Start-up costs (depending on the switch-off duration), Power proportional costs, Output decrease costs, Penalties for the maximal number of start ups, output variations, and deep output decrease per day

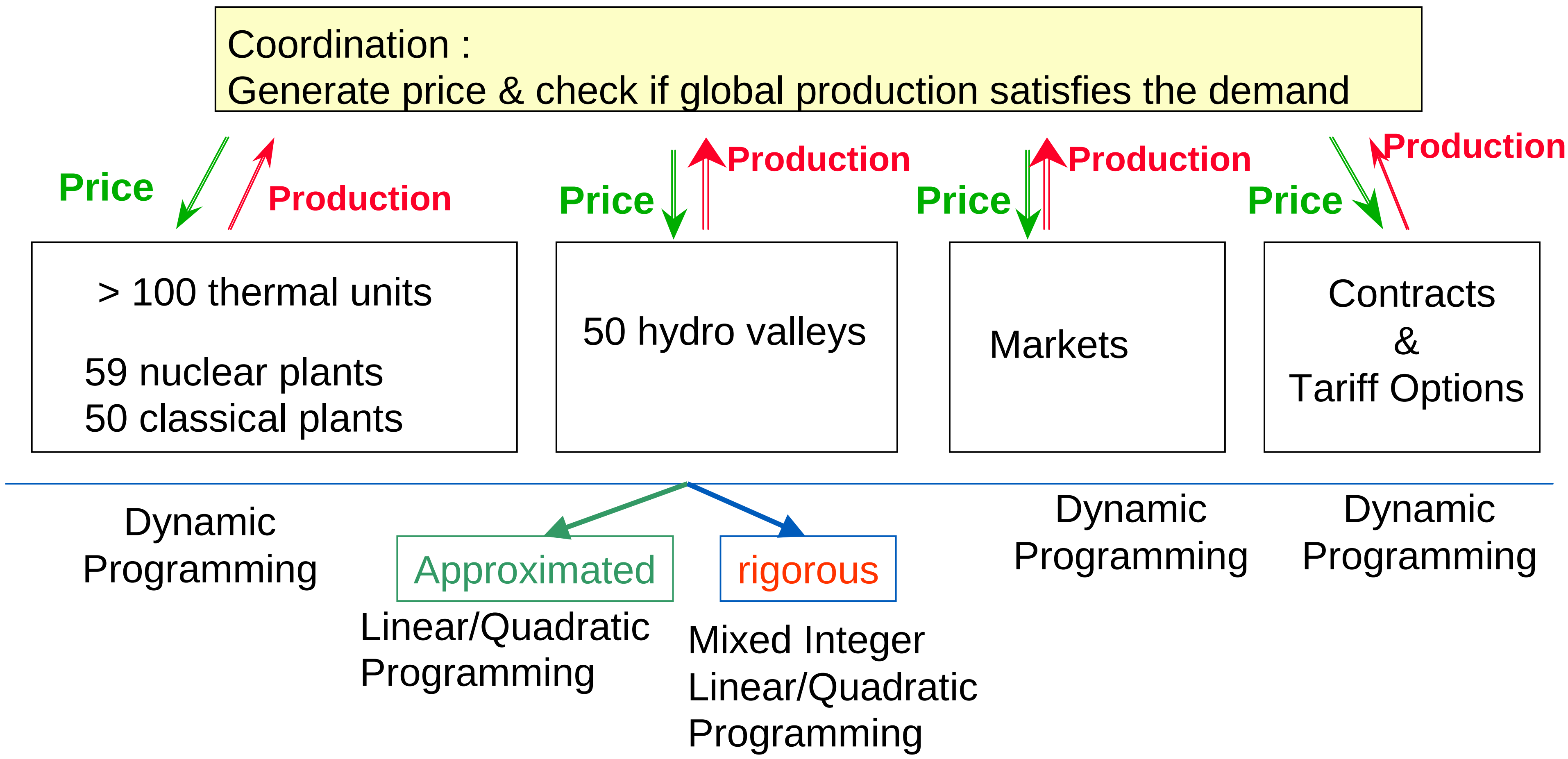
Decision variables : production planning of each plant and economical indicators (marginal costs)

Constraints :

- **Satisfy the demand** (coupling constraint)
- **Thermal constraints** : Minimum duration of production, Start-up and switch-off curves, Bound constraints on output variation, Maximal number of start ups, output variations, and deep output decrease per day
- **hydro constraints** : Cost = global loss of water (water values), Bound constraints on reservoir volumes, power plants flows and generation (depending on time), Hydraulic inflows, Flow constraints : waters turbined in a plant goes to the downstream reservoir within a certain delay

Mixt-integer, nonlinear, nonconvex optimization problem of big size :
From 200 000 to 300 000 variables, 500 000 constraints

Resolution : Price Decomposition & Clustering



High degree of parallelizing (about 250 units)

A problem which can be considered as solved…

COOPERATIONS :

Claude Lemaréchal, Claudia Sagastizabal, INRIA

Guy Cohen, CERMICS

→ **Operational tool used every day at EDF**

… but many challenging features remain

Challenge 1 : the hydro sub-problem

We considered the simplified version of the hydro sub-problem

$$\min_{V,T} J(V,T) = \sum_{l=1}^{L} \omega_l \left(V_l^o - V_l^K\right) - \sum_{k=1}^{K}\sum_{i=1}^{I}\sum_{j=1}^{J} \lambda^t \rho_{j(i)} \mathrm{T}_{j(i)}^k$$

Own cost - Earning

A LP

$$V_l^k = V_l^{k-1} + \sum_{ij\in M} \mathrm{T}_{ij}^{k-d_{ij}^l} - \sum_{ij\in V} \mathrm{T}_{ij}^{k+d_{ij}^l} + \mathrm{A}_l^k$$

Flow Assessment

$$\begin{cases} \min z = c^t x \\ Ax = b \\ x_i \geq 0 \end{cases}$$

$$0 \leq \mathrm{T}_{ij}^k \leq \mathrm{T}_{ij}^{max}, \quad \forall k \in \{1,\dots,K\}$$

$$V_l^{min} \leq V_l^k \leq V_l^{max}, \quad \forall k \in \{1,\dots,K\}$$

Bounds

Challenge 1 : the hydro sub-problem

The Realistic Hydro Subproblem : A huge MIP

Motivation : Big economical stakes of Hydro-Power : 200 to 300 Millions € / year

C1 : Discrete nature of hydro-production

C2 : Forbidden to reduce the hydro-production during a certain number of time steps

$$\forall t, (T_u^t - T_u^{t-1})(T_u^{t+1} - T_u^t) \geq 0 \qquad \forall t, -1 \leq 2e_{u,g}^t - e_{u,g}^{t-1} - e_{u,g}^{t+1} \leq 1$$

C3 : Bounds on flow gradients

$$\underline{\delta_u^t} \leq T_u^{t+1} - T_u^t \leq \overline{\delta_u^t} \qquad \underline{\delta_u^t} \leq \sum_{g=1}^{G(u)} (e_{u,g}^{t+1} - e_{u,g}^t)\overline{T_{u,g}} \leq \overline{\delta_u^t}$$

C4 : Forbidden to simultaneous turbining and pumping

$$\forall t, T_{ut}^t . T_{up}^t = 0 \qquad e_{ut,g1}^t + e_{up,g'1}^t \leq 1$$

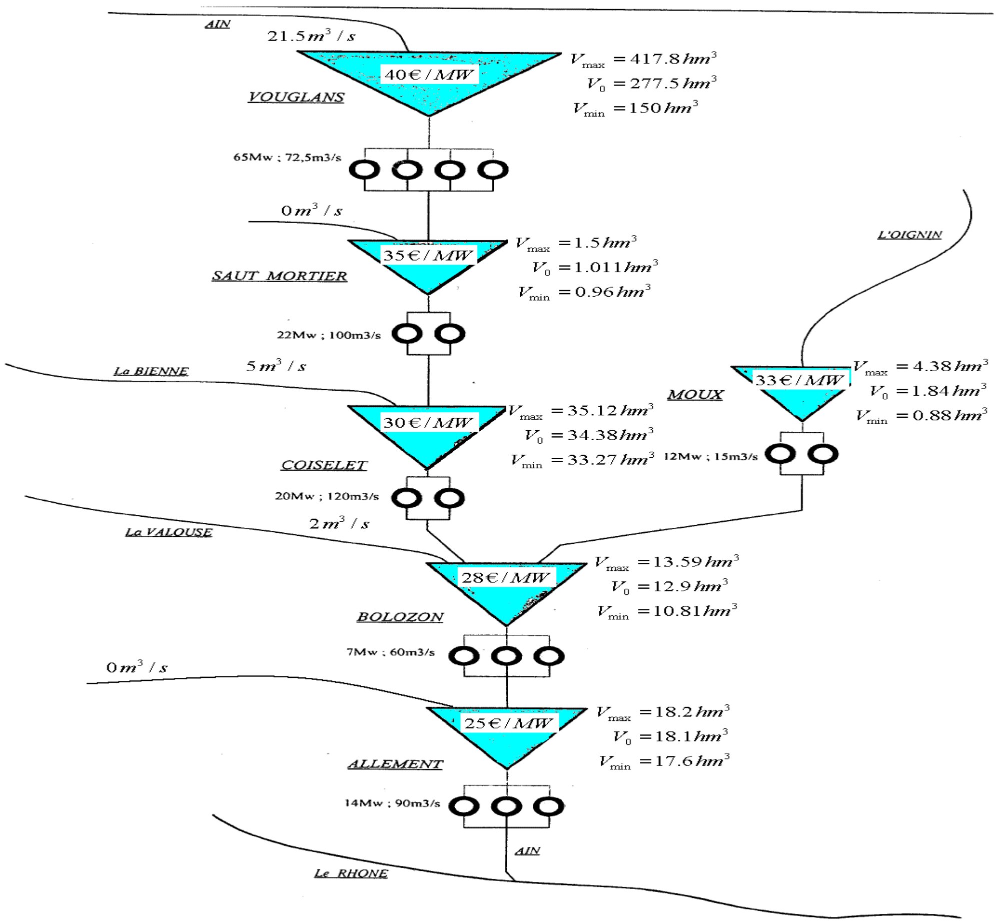
Challenge 1 : the hydro sub-problem

The Realistic Hydro Subproblem : A huge MIP

Small size valley	La Romanche : 13000 unknowns 10000 constraints (3000 binary variables)
Medium size valley	L'Arc : 15000 unknowns 12000 constraints (4000 binary variables)
Big size valley	La Durance : 18000 unknowns 13000 constraints (5000 binary variables)

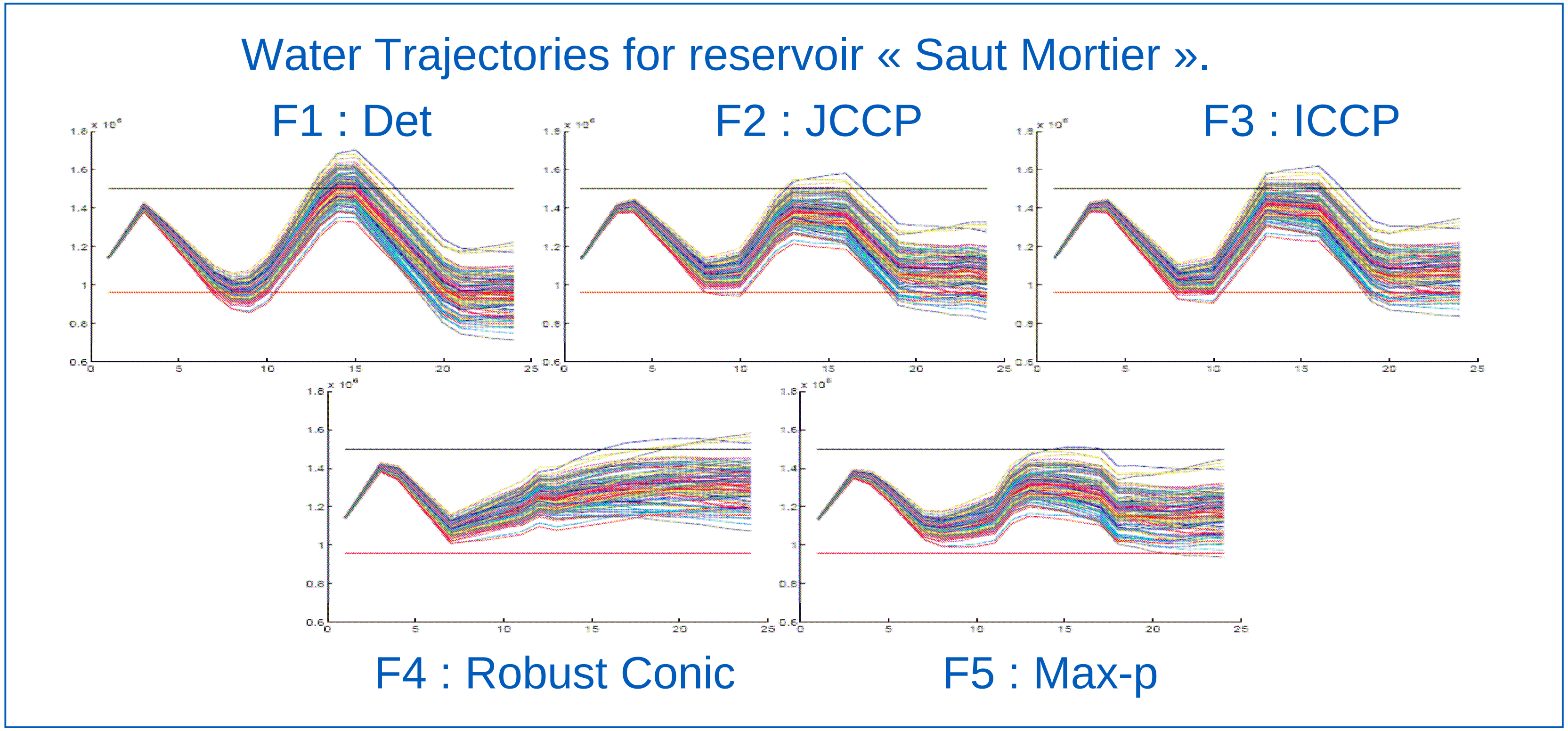
Challenge 2 : What about uncertainty ?

To determine the production levels of a valley associated to a given price signal
When taking uncertainty on inflows into account



Challenge 2 : What about uncertainty ?

"Toy" Problem 2 Second experiment on chance constrained programming



Inst.	Item / Problem	Det	JCCP	ICCP	Conic	Max-p
2	nbViolation	100	20	35	4	2
2	Cost (€)	$-1.0478e^5$	$-1.0340e^5$	$-1.0422e^5$	$-1.0282e^5$	$-9.9176e^4$

JCCP : nice tradeoff between cost and robustness

The Intra-Day Optimization : a « recourse »

D-1 : forecasted planification of production for [D, D+1]

Forecasted data at D-1 for D

d_0 →

D_0 →

$$\min_{x \in X} f(x) \qquad \textbf{JO}$$

$$\sum_{j=1}^{n} x_{ij}^0 = d_i^0 \qquad i = 1, \ldots, m$$

→ **Economical Indicators** (z_0, λ_0)

→ **Planning of production** X_0

n **Production units** (→)

m **Time step** (↓)

$$X_0 = \begin{bmatrix} x_{11}^0 & & x_{1j}^0 & & x_{1n}^0 \\ x_{i1}^0 & \ldots & x_{ij}^0 & \ldots & x_{in}^0 \\ x_{m1}^0 & & x_{mj}^0 & & x_{mn}^0 \end{bmatrix}$$

The Intra-Day Optimization : a « recourse »

D1 : D – recourse 1 : adjustment of the planning to the real demand at D1

Observed data at D1

d_1

D_1

X_0

ID

$$\min_{x^1 \in X, y \in \{0,1\}^n} f\left(x^1\right)$$

$$\sum_{j=1}^{n} x_{ij}^1 = d_i^1 \quad i = 1, \dots, m$$

$$\sum_{j=1}^{n} y_j \leq N = 30$$

$$\left| X_j^1 - X_j^0 \right| \leq yM$$

Economical Indicators

$$\left(z_0, \lambda_0 \right)$$

Adjusted Planning of Production for D1

X_1

$$X_1 = \begin{bmatrix} x_{11}^1 & & x_{1j}^1 & & x_{1n}^1 \\ x_{i1}^1 & \dots & x_{ij}^1 & \dots & x_{in}^1 \\ x_{m1}^1 & & x_{mj}^1 & & x_{mn}^1 \end{bmatrix} = \left[\begin{bmatrix} x_{11}^{y_1} \\ x_{i1}^{y_1} \\ x_{m1}^{y_1} \end{bmatrix} y_1 \quad \dots \quad \begin{bmatrix} x_{1j}^{y_j} \\ x_{ij}^{y_j} \\ x_{mj}^{y_j} \end{bmatrix} y_j \quad \dots \quad \begin{bmatrix} x_{1n}^{y_n} \\ x_{in}^{y_n} \\ x_{mn}^{y_n} \end{bmatrix} y_n \right]$$

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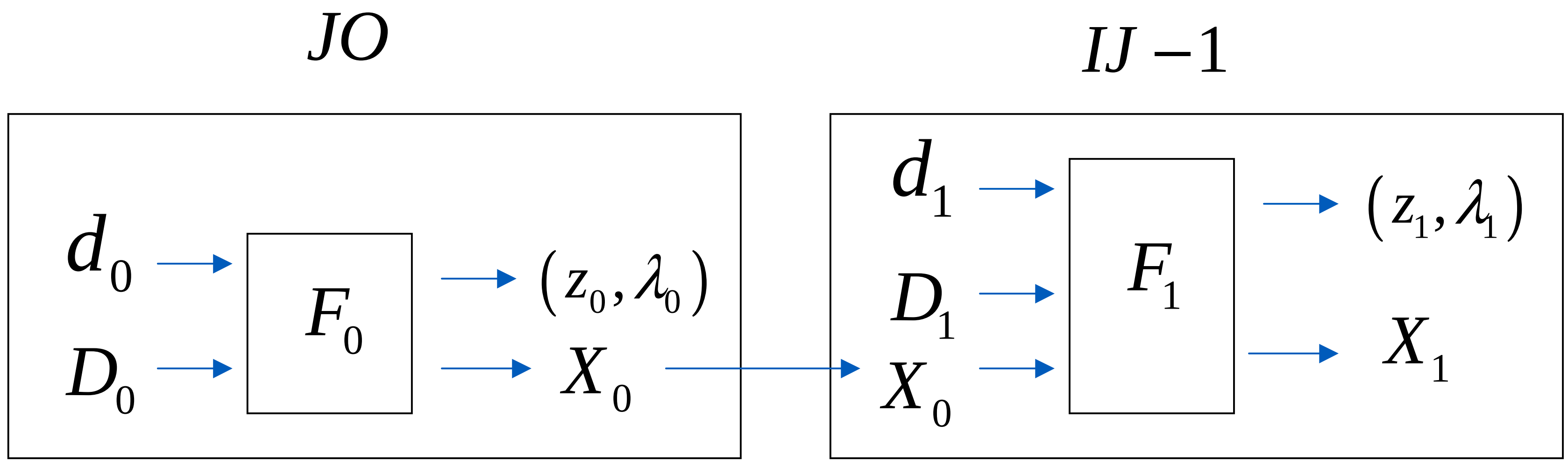
The Intra-Day Optimization : a « recourse »

The ID Processus now is not effcient



Difficulty : CPU(ID) too long

(90 min instead of 2 / 3 minutes required).

The Intra-Day Optimization : a « recourse »

Production Units

Time

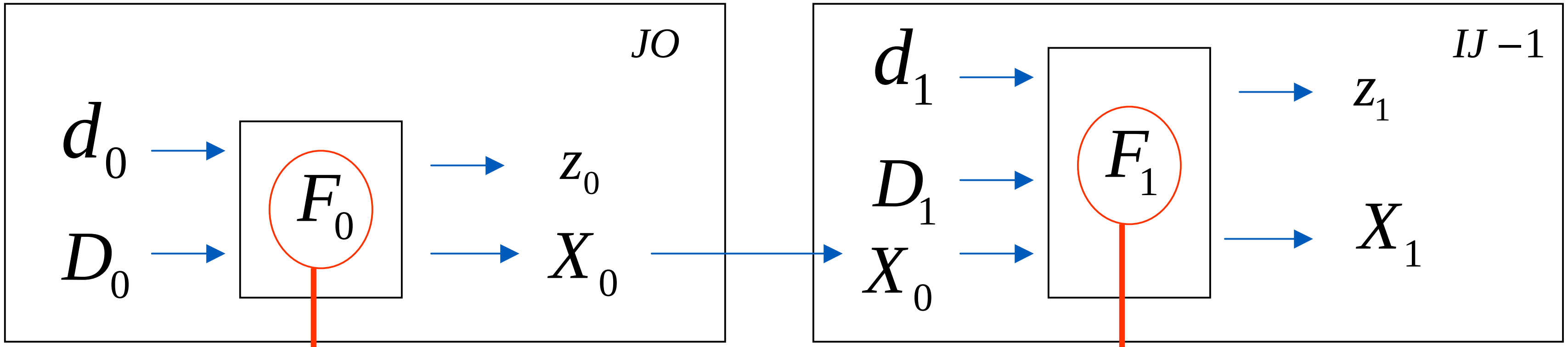
$$X_1 = \begin{bmatrix} x_{11}^1 & & x_{1j}^1 & & x_{1n}^1 \\ x_{i1}^1 & \dots & x_{ij}^1 & \dots & x_{in}^1 \\ x_{m1}^1 & & x_{mj}^1 & & x_{mn}^1 \end{bmatrix} = \left[\begin{bmatrix} x_{11}^{y_1} \\ x_{i1}^{y_1} \\ x_{m1}^{y_1} \end{bmatrix} y_1 \quad \dots \quad \begin{bmatrix} x_{1j}^{y_j} \\ x_{ij}^{y_j} \\ x_{mj}^{y_j} \end{bmatrix} y_j \quad \dots \quad \begin{bmatrix} x_{1n}^{y_n} \\ x_{in}^{y_n} \\ x_{mn}^{y_n} \end{bmatrix} y_n \right]$$

ID request : Adjustment of initial planning of production X^0 must affect a limted number of individual plannings of production (30 maximum).

The difference of plannings matrix $X^1 - X^0$ must have a lot of zeroed columns (no change of the planning of the majority of production units.

The Intra-Day Optimization : a « recourse »

ID : a problem of « Group Sparsity » ? Experiment



$$\min_{x_0 \in \mathbb{R}^n} c^T x_0$$
$$Ax_0 \geq b_0$$
$$x_0 \geq 0$$

$$\min_{x_1 \in \mathbb{R}^n} c^T x_1$$
$$Ax_1 = b_1$$
$$\sum_{j=1}^{n} y_j \leq N = 30, \quad \left| X_j^1 - X_j^0 \right| \leq yM$$
$$x_1 \geq 0, \quad y \in \{0,1\}^n$$

Processing F1 using a Group Sparsity technique

The Intra-Day Optimization : a « recourse »

Group Sparsity

Group sparsity refers to requirements on the decision variable of an optimization problem, which enforces some groups of variables to be zero.

It is best described when the decision variable is a $m\ n$ matrix X; in that context, a group sparsity requirement would typically ask that many columns of X be zero.

This kind of requirement is distinct from that asking for a sparse matrix X, since the latter would potentially allow zeroes to be ”sprinkled” over all the columns.

In energy management, such group sparsity requirements arise naturally when the decision variable is a matrix, where each row correspond to a specific production resource (such as a water turbine in an hydroelectric valley), and each column is a time instant. Contractual and other constraints lead to requirements that, when re-planning a problem, most of the production resources be assigned the same production levels.

The Intra-Day Optimization : a « recourse »

Group Sparsity

Application to Infra-day Problem :

Production units →

↓ Time steps

$$X = \begin{bmatrix} x_{11} & & x_{1n} \\ x_{i1} & x_{ij} & x_{in} \\ x_{m1} & & x_{mn} \end{bmatrix}$$

Requirement : the matrix $X^1 - X^0 = X - X^{previous}$ must be « row-sparse » :

most of the rows in X^1 should remain the same as the corresponding one in X^0

The Intra-Day Optimization : a « recourse »

Group Sparsity

Basic model : optimization of the form

$$\min_{w} \; f(X^T w) + \lambda \sum_{i \geq 1}^{K} \|w_i\|_2 \qquad \textbf{(1)}$$

f loss function

X data matrix

$\lambda > 0$ penalty parameter

$w \geq (w_1, \ldots, w_K)$ optimization variable, which is decomposed into sub-blocks

$$w_i, \; i \geq 1, \ldots, K$$

$\lambda \sum_{i \geq 1}^{K} \|w_i\|_2$ penalty term : encourages entire blocks to be zero

The Intra-Day Optimization : a « recourse »

Toy Problem 3

Generation of 25 units (nuclear, coal, fuel, gas, combustion turbines TAC) should satisfy the demande at minimal cost for the next 24 hours.

15 Nuclear : 1 REP 1500 + 5 REP 1300 + 9 REP 900

2 Coal : 1 CH 600 + 1 CH 250

5 Fuel : 1 FL 600 + 4 FL 250

1 Gas : 1 GZ 100

2 TAC : 1 TAC 86 + 1 TAC 114

Capacity constraints, impositions; no dynamical constraint

The Intra-Day Optimization : a « recourse »

Toy Problem 3

Costs [€/MWh]

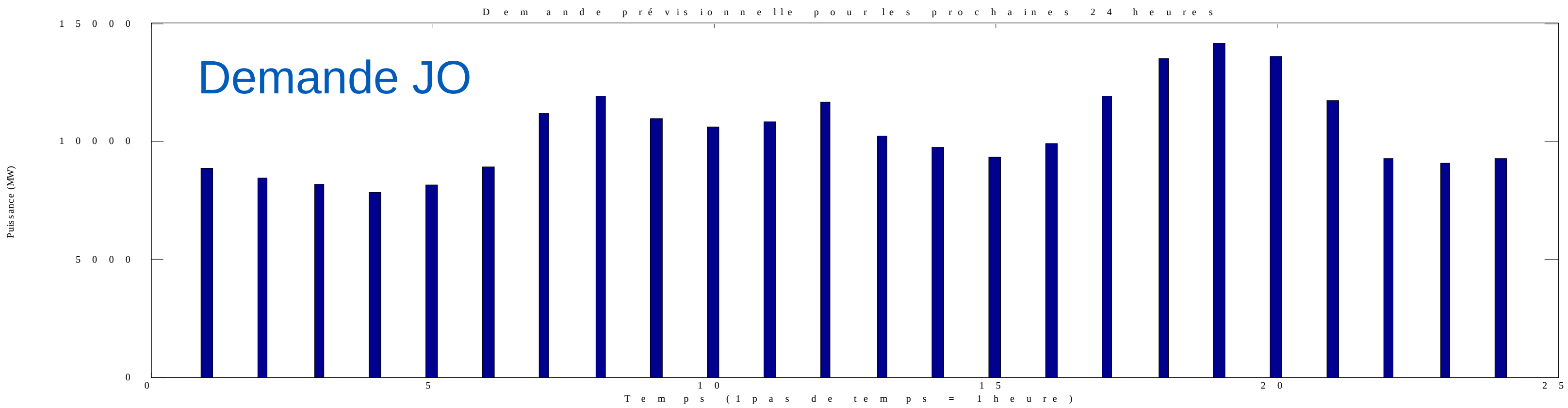
REP 1500	:	4 - 8
REP 1300	:	4 - 10
REP 900	:	4 – 11
CH 600	:	43 - 54
CH 250	:	45 - 55

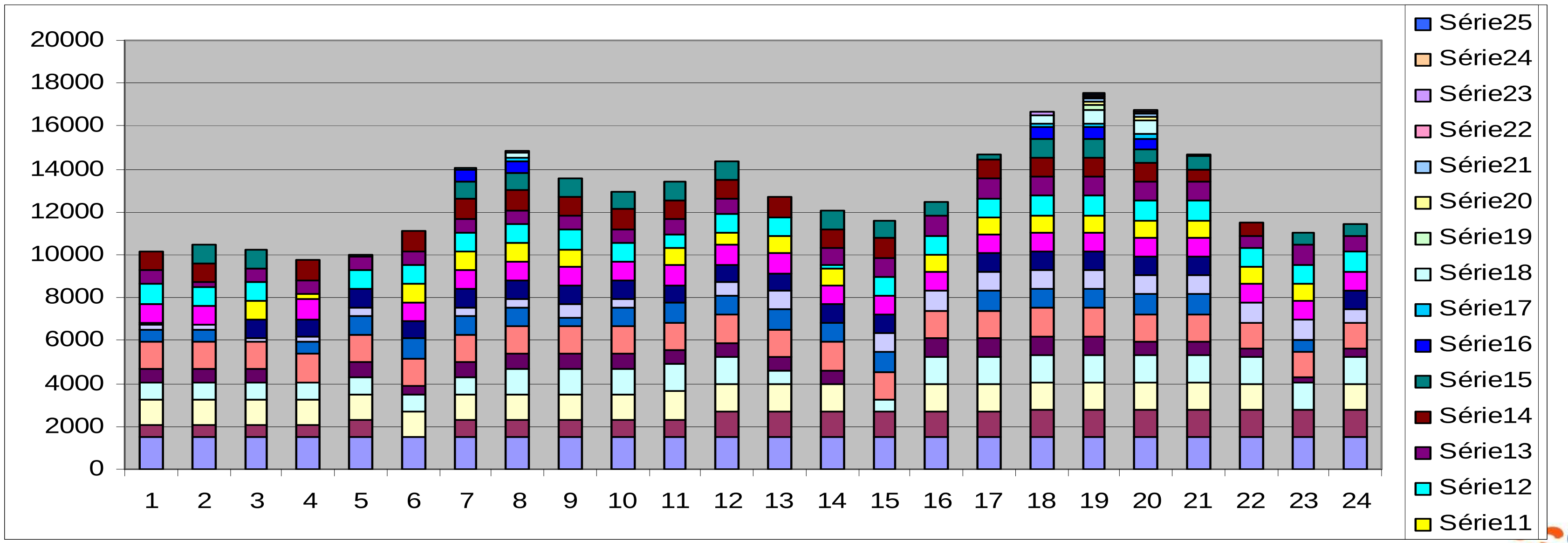
FL 600	:	80 - 90
FL 250	:	84 - 87
Gaz	:	65 - 70
TAC	:	120 - 130

The Intra-Day Optimization : a « recourse »

Toy Problem 3

Demande et Planning de production JO





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The Intra-Day Optimization : a « recourse »

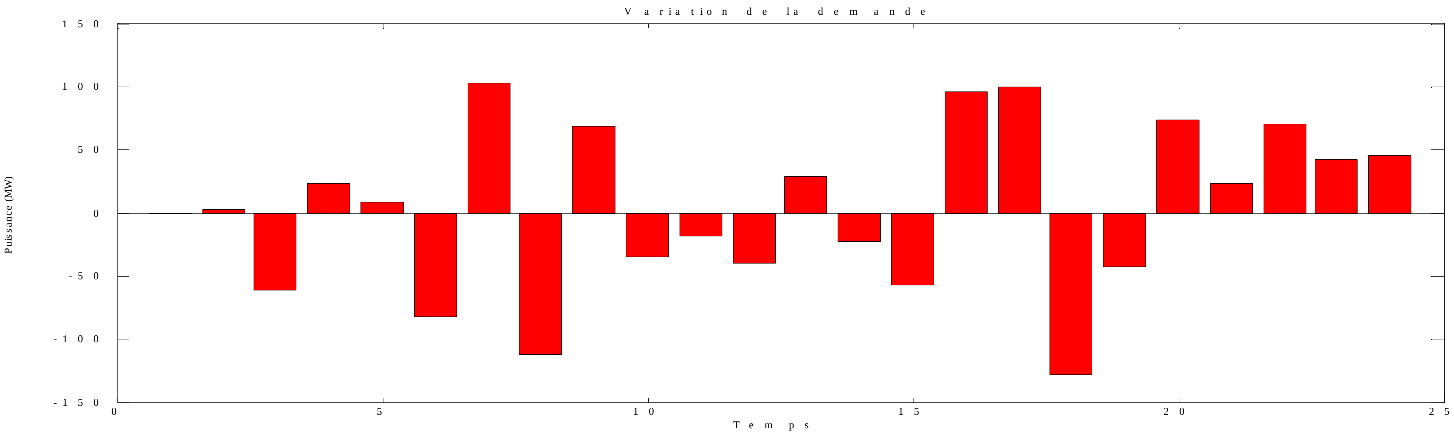
Toy Problem 3

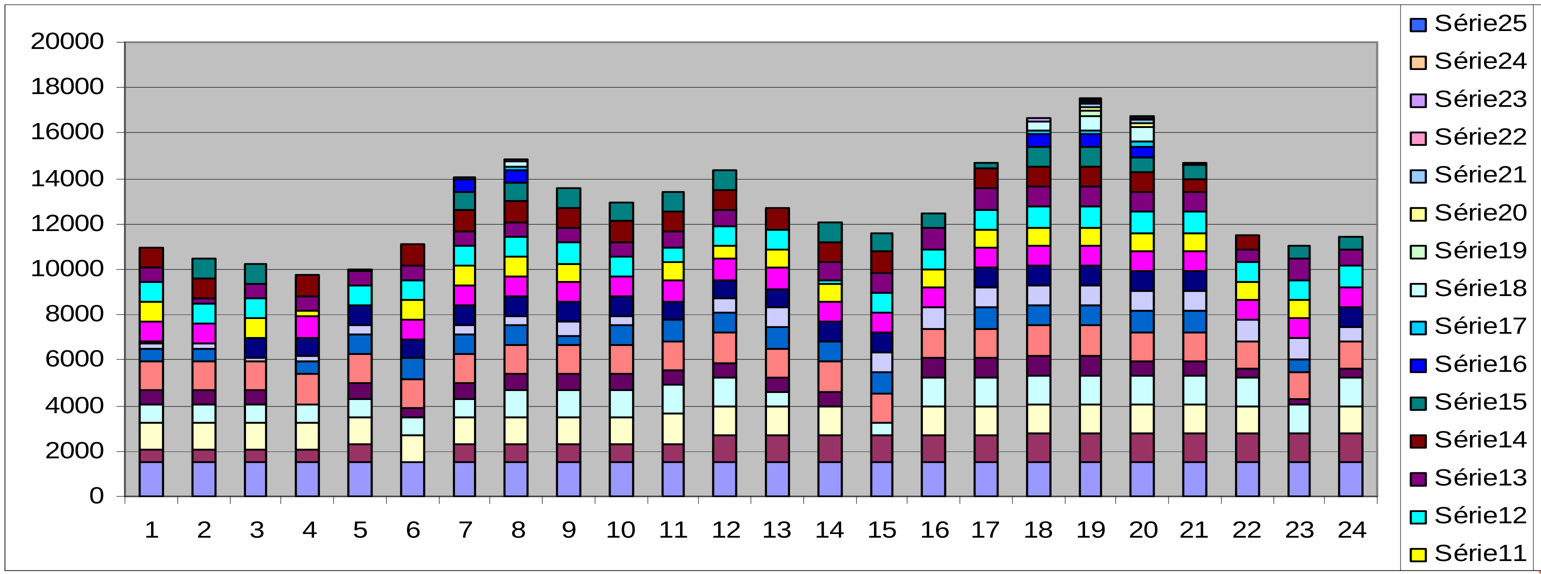
Planning de production JO

1500	1300					900									600	250	600	250				100	86	114
1470	600	1200	800	650	1200	600	200	97	890	30	890	650	900	0	0	0	0	0	0	0	0	0	0	0
1470	600	1200	800	650	1200	600	200	0	890	0	890	222	900	850	0	0	0	0	0	0	0	0	0	0
1470	600	1200	800	650	1200	0	200	850	45	830	890	650	0	850	0	0	0	0	0	0	0	0	0	0
1470	600	1200	800	0	1300	600	200	850	890	286	0	650	900	0	0	0	0	0	0	0	0	0	0	0
1470	850	1200	800	650	1300	900	400	850	0	0	890	650	0	73	0	0	0	0	0	0	0	0	0	0
1470	0	1200	800	404	1300	900	0	850	890	830	890	650	900	0	0	0	0	0	0	0	0	0	0	0
1470	850	1200	800	650	1300	900	400	850	890	830	890	650	900	850	530	123	0	0	0	0	0	0	0	0
1470	850	1200	1200	650	1300	900	400	850	890	830	890	650	900	850	530	200	178	0	0	0	0	100	0	0
1470	850	1200	1200	650	1300	426	600	850	890	830	890	650	900	850	0	0	0	0	0	0	0	0	0	0
1470	850	1200	1200	650	1300	900	370	850	890	0	890	650	900	850	0	0	0	0	0	0	0	0	0	0
1470	850	1305	1280	650	1300	900	0	850	890	830	654	650	900	850	0	0	0	0	0	0	0	0	0	0
1470	1200	1305	1280	650	1300	900	600	850	890	606	890	650	900	850	0	0	0	0	0	0	0	0	0	0
1470	1200	1305	598	650	1300	900	890	850	890	830	890	0	900	0	0	0	0	0	0	0	0	0	0	0
1470	1200	1305	0	650	1300	900	0	850	890	830	126	800	900	850	0	0	0	0	0	0	0	0	0	0
1470	1200	0	582	0	1300	900	890	850	890	0	890	890	900	850	0	0	0	0	0	0	0	0	0	0
1470	1200	1305	1280	850	1300	0	890	0	890	830	890	890	0	649	0	0	0	0	0	0	0	0	0	0
1470	1200	1305	1280	850	1300	900	890	850	890	830	890	890	900	270	0	0	0	0	0	0	0	0	0	0
1470	1300	1305	1280	850	1300	900	890	850	890	830	890	890	900	850	530	225	395	0	0	0	0	100	0	0
1470	1300	1305	1280	850	1300	900	890	850	890	830	890	890	900	850	530	225	600	225	200	138	80	100	0	56
1470	1300	1305	1280	600	1300	900	890	850	890	830	890	890	900	600	530	225	600	0	190	138	80	100	0	0
1470	1300	1305	1280	600	1300	900	890	850	890	830	890	890	600	600	78	0	0	0	0	0	0	0	0	0
1470	1300	1200	1280	400	1200	0	890	0	890	830	890	532	600	0	0	0	0	0	0	0	0	0	0	0
1470	1300	0	1280	205	1200	600	890	0	890	830	890	890	0	600	0	0	0	0	0	0	0	0	0	0
1470	1300	1200	1280	400	1200	0	650	850	890	0	890	710	0	600	0	0	0	0	0	0	0	0	0	0
Nucléaire															CH		Fioul					GZ	TAC	

The Intra-Day Optimization : a « recourse »

Toy Problem 3 **Variation of the demand of +/- 1%**
And adjustment of the planning of production





The Intra-Day Optimization : a « recourse »

Toy Problem 3

12 redeclarations

1500	1300					900									600	250	600	250				100	86	114
0	0	0	0	0	0	0	0	0	0	0	0	0	0	-1	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	-48	0	0	-6	0	0	0	-25	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-34	0	0	-30	0	0	0	0	0	0	-38	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	91	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-128	0	0	0	0	0	0	0
0	0	0	0	0	0	48	0	0	0	0	0	0	0	38	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-30	0	0	-14	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	-51	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	7	0	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	-30	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	-34	0	0	0	0	0	-38	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	31	0	0	0	0	0	51	0	0	0	38	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	30	0	6	51	0	0	0	38	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-128	0	0	-19	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-50
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	66	0	0	19	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0	0	0	0	0	0	0	0	0
0	0	0	0	34	0	0	0	0	0	51	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	34	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	0	0	0	0	0
0	0	0	0	21	0	0	30	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	1	0	1	1	0	1	1	0	0	1	1	1	1	1	0	0	1	0	0	0	1
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25
Nucléaire															CH		Fioul					GZ	TAC	

The Intra-Day Optimization : a « recourse »

Group Sparsity : A promising technique ?

We just add a term in the objective-function

Better complexity $\overset{JO}{LP}$ → $\overset{IJ-1}{SOCP}$ Instead of MIP

How to master the number of redeclarations ? : shreshold on small adjustments ?

What about a more realistic model (MIP) for Daily process instead of a LP ?

Problème-jouet N°1 de gestion de la production

4 centrales (nucléaire, charbon, fioul, gaz) doivent satisfaire la demande au moindre coût sur les 3 prochains pas de temps.

Coûts	Bornes	Demande initiale	Disponibilité
$C = \begin{bmatrix} 22 & 55 & 68 & 94 \\ 28 & 45 & 73 & 83 \\ 24 & 51 & 74 & 78 \end{bmatrix}$	$0 \leq X \leq \begin{bmatrix} 850 & 450 & 350 & 150 \\ 850 & 280 & 250 & 150 \\ 750 & 650 & 230 & 150 \end{bmatrix}$	$b_0 = \begin{bmatrix} 1192 \\ 1128 \\ 1293 \end{bmatrix}$	$AD = \begin{bmatrix} 0.75 & 0.71 & 0.92 & 0.78 \\ 076 & 0.74 & 0.91 & 0.76 \\ 078 & 0.73 & 0.93 & 0.75 \end{bmatrix}$

Problème-jouet N°1 de gestion de la production

Processus JO : un PL

$$\min_{x_0 \in \mathbb{R}^n} c^t x_0$$
$$A x_0 \geq b_0$$
$$x_0 \leq x_0^{max}$$
$$x_0 \geq 0$$

Processus IJ : un MIP

$$\min_{x_1 \in \mathbb{R}^n} c^T x_1$$
$$A x_1 \geq b_1$$
$$\sum_{j=1}^{n} y_j \leq N = 2, \quad \left| X_j^1 - X_j^0 \right| \leq yM$$
$$x_1 \geq 0, \quad y \in \{0,1\}^n$$

Processus IJ : un SOCP

$$\min_{X_1} \langle C, X_1 \rangle + \lambda \left\| X_1 - X_0 \right\|_\infty$$
$$\langle A_i, X_1 \rangle \geq b_{1i}$$
$$X_1 \leq X_{max}$$
$$X_1 \geq 0$$

$$b_0 = \begin{bmatrix} 1192 & 1128 & 1293 \end{bmatrix}^T$$

$$z^* = 190534 \text{ €}$$

$$X_0 = \begin{bmatrix} 850 & 327.46 & 350 & 0 \\ 850 & 280 & 250 & 62.23 \\ 750 & 650 & 230 & 26.13 \end{bmatrix}$$

$$b_1 = \begin{bmatrix} 1170 & 1140 & 1346 \end{bmatrix}^T$$

$$z^* = 195652 \text{ €}$$

$$X_1 = \begin{bmatrix} 850 & 296.48 & 350 & 0 \\ 850 & 280 & 250 & 78.02 \\ 750 & 650 & 230 & 96.80 \end{bmatrix}$$

Problème-jouet N°1 de gestion de la production

Processus IJ : un MIP

$$\min_{x_1 \in \mathbb{R}^n} c^T x_1$$

$$Ax_1 \geq b_1, \quad \sum_{j=1}^{n} y_j \leq N = 1, \quad \left| X_j^1 - X_j^0 \right| \leq yM$$

$$x_1 \geq 0, \quad y \in \{0,1\}^n$$

Pas de solution MIP avec N=1

Solution relaxée avec N=1 :

- plus chère que la solution « Group Sparsity » : $z^* = 195671$ €

- 3 redéclarations !

$$X_1 = \begin{bmatrix} 850 & 303.71 & 344.41 & 0 \\ 850 & 280 & 250 & 78.02 \\ 750 & 650 & 230 & 96.80 \end{bmatrix}$$

Problème-jouet N°1 de gestion de la production

Variation de la demande -/+ 5 % : loi uniforme dans intervalle par rapport à b_0

$$b_1 = \begin{bmatrix}1234 & 1121 & 1345\end{bmatrix}^T \qquad z^* = 198431 \text{ €} \qquad X_1 = \begin{bmatrix}850 & 386.62 & 350 & 0 \\ 850 & 280 & 250 & 53.02 \\ 750 & 650 & 230 & 95.46\end{bmatrix}$$

Variation de la demande -/+ 1 % : loi uniforme dans intervalle par rapport à b_0

$$b_1 = \begin{bmatrix}1184 & 1124 & 1284\end{bmatrix}^T \qquad z^* = 188542 \text{ €} \qquad X_1 = \begin{bmatrix}850 & 316.19 & 350 & 0 \\ 850 & 280 & 250 & 56.97 \\ 750 & 650 & 230 & 14.13\end{bmatrix}$$

5

What about Smart Grids ?

Smart Grids

Main actors of electricity business

- utilities,
- network managers
- customers.

Electricity is produced by power units distributed in a territory and transported with a high voltage network to substations.

A substation = interface between the high voltage transportation network and the low voltage distribution network (customers).

Producers must meet the demands of their customers by providing the needed electrical energy to the distributor (the low voltage network manager).

This network manager distributes the electric power from the substations to the customers.

Smart Grids

Network manager : determines the network sizing (appropriate infrastructure to the community energized to ensure access for all producers to the grid).

Sizing substations, based on the maximum consumption drawn off, is economically Costly : the maximum power that can pass through the substation is a rare event, reached essentially the coldest days of winter.

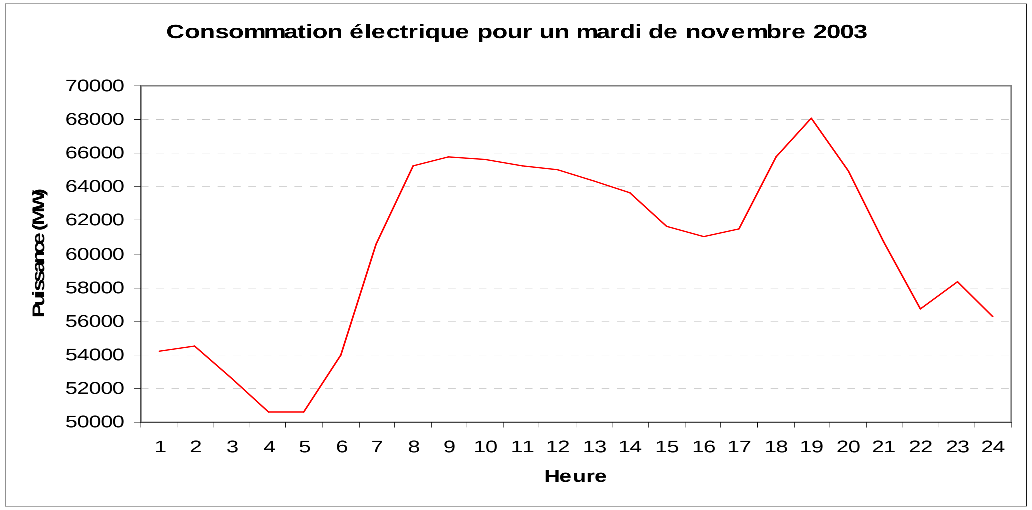
One way to address the problem of sizing is to act on the load curve observed at the substations, especially on peak demand. This question leads therefore the problem of smoothing the load curve at the substations.

This is sort of shifting some of the customers so that they can better spread over the day. The goal is to reduce peak demand.

Challenging Optimization Problem for Smart Grids

Additional difficulty : using price signals (peak and off-peak tariffs), optimize the management of peaks of the load curve in the view

- to reduce the need to use expensive production units for satisfying the demand
- to limit the risk of black-out



$$\min_{x \in X, y \in Y} f(x, y, \xi)$$

$$A(x, \xi_A) x \geq b(y, \xi_b)$$

$$F(x) \leq 0$$

$$G(y) \leq 0$$

Conclusion

A lot of research work to do with huge stakes

Energy management problems

- **Operations research & optimization with challenging features**
- **approximate solutions**
- **robust solutions**
- **parallel & clustering computing**

A changing world

- **environment constraints**
- **new technologies (Linky meters & Smart Grids)**
- **climate**