MIXOPTIM: A MONTE CARLO SIMULATION TOOL FOR THE EVALUATION AND OPTIMIZATION OF AN ELECTRICITY MIX

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Post-doctoral position
CEA Cadarache

MIXOPTIM team:

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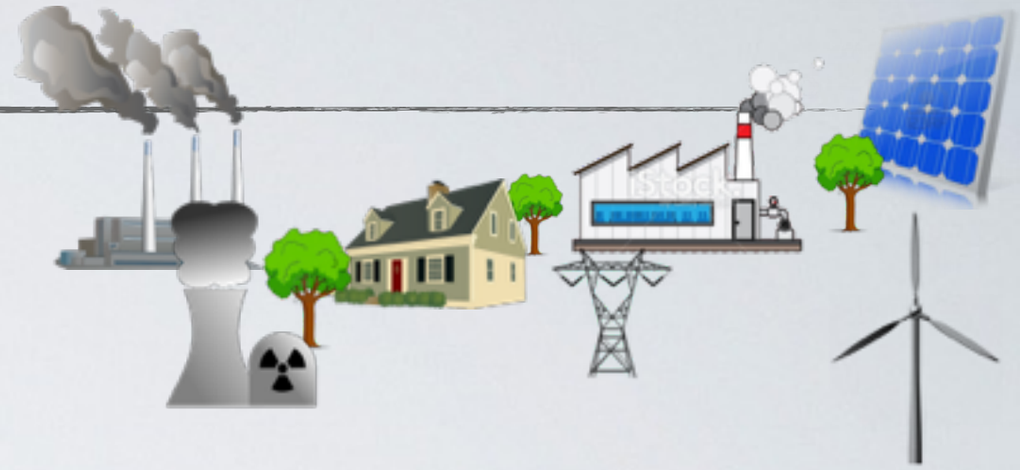
CNRS - *E. Merle*

IRSN - *O. Jacquet, J. Miss, Y. Richet*

Alliance Nationale de Coordination de la Recherche pour l'Énergie

Outline



I. Electricity MIX

II. MIXOPTIM
- General approach
- Mix study
- Scenarios

III. Ongoing developments
- Energy storage
- OPTIMIX project - NEEDS program

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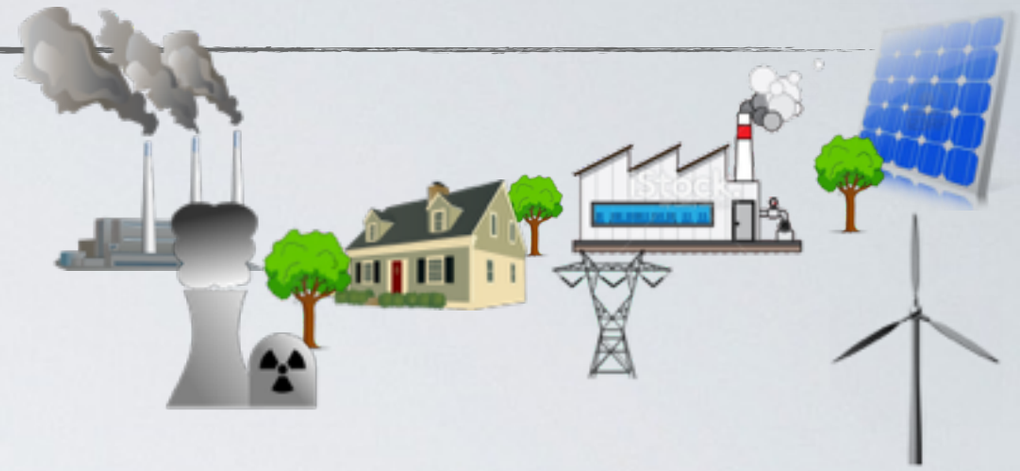
ELECTRICITY MIX



Context:

- the power demand must be satisfied
- different ways to produce energy

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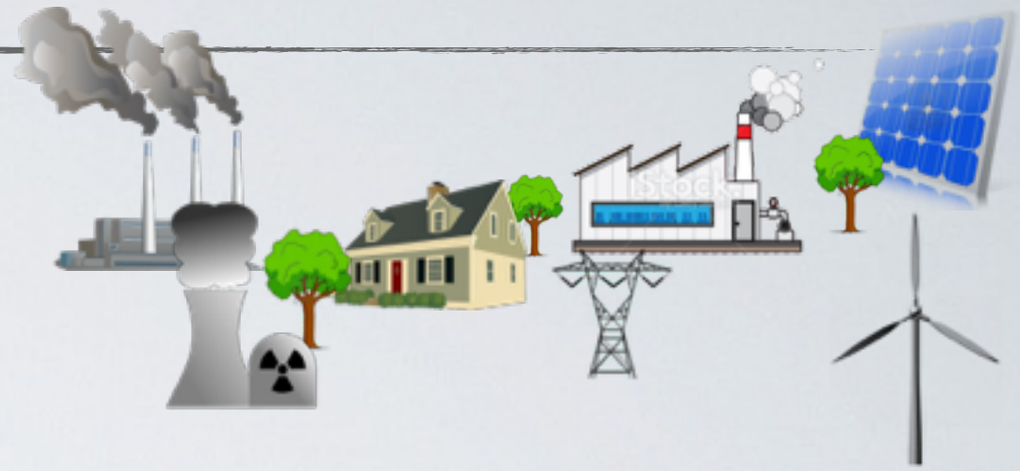

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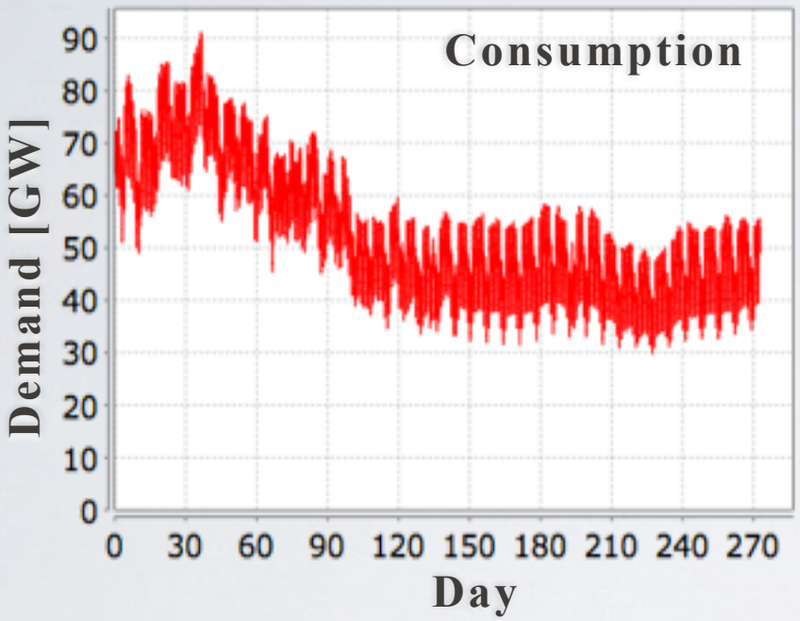

[source : RTE - 2015]

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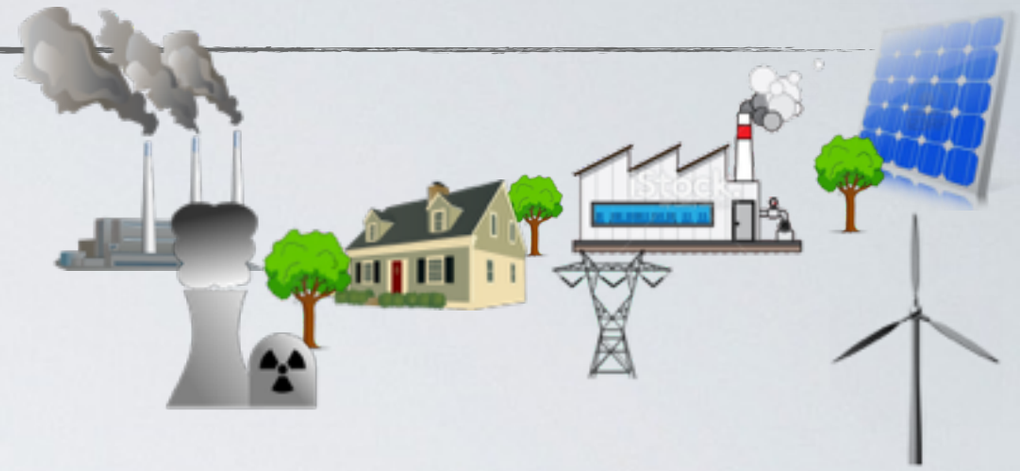

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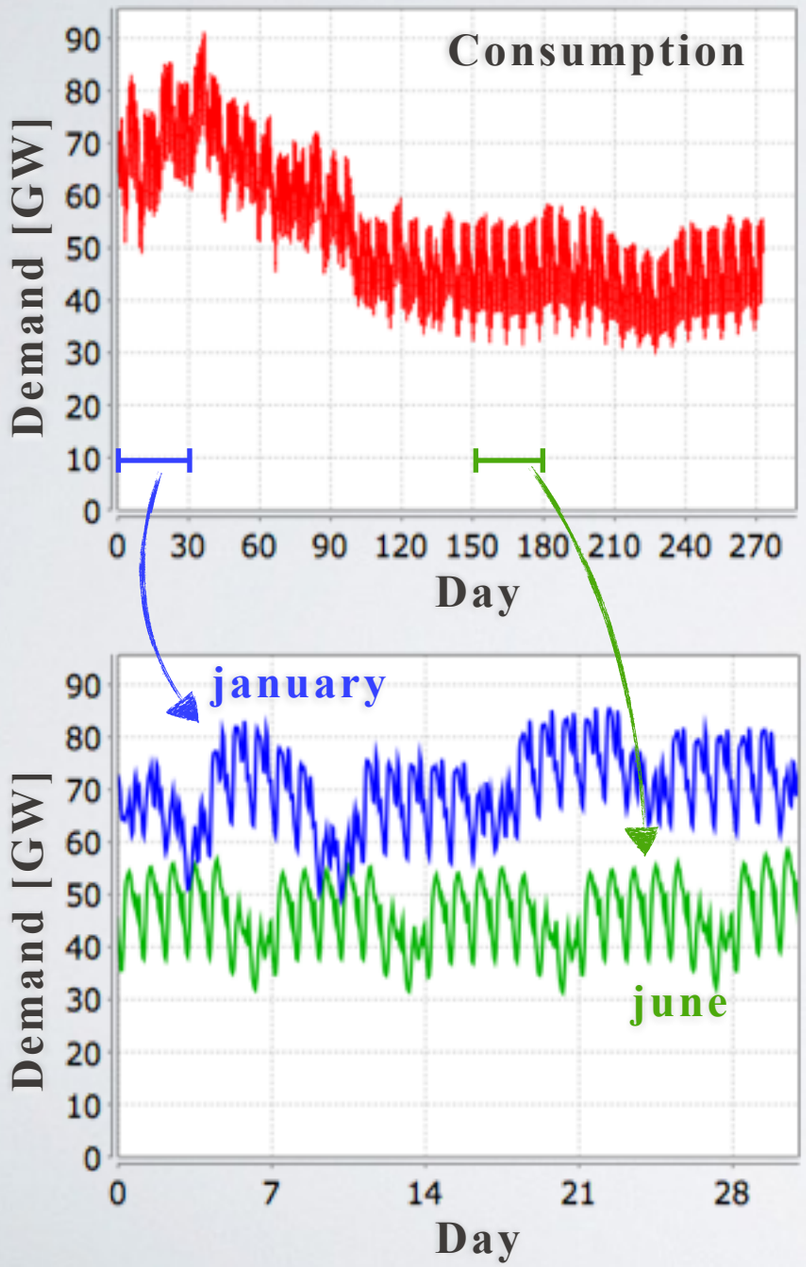

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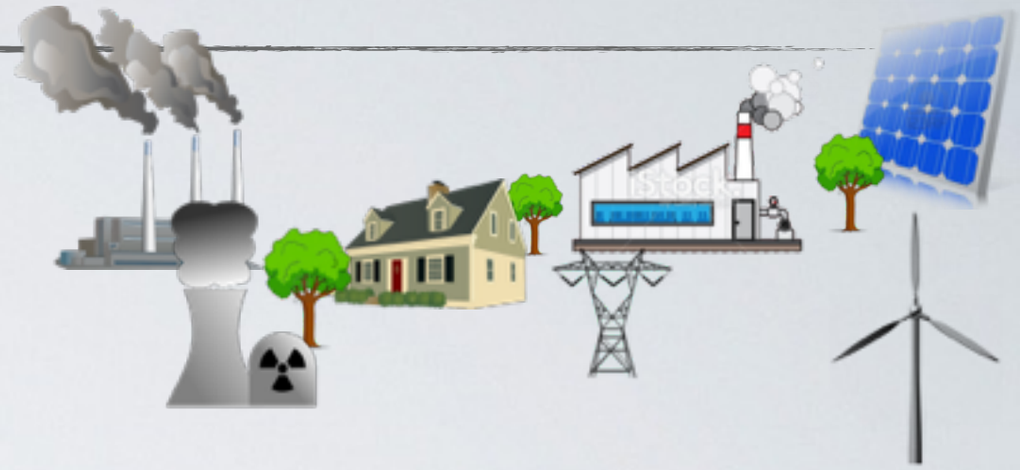

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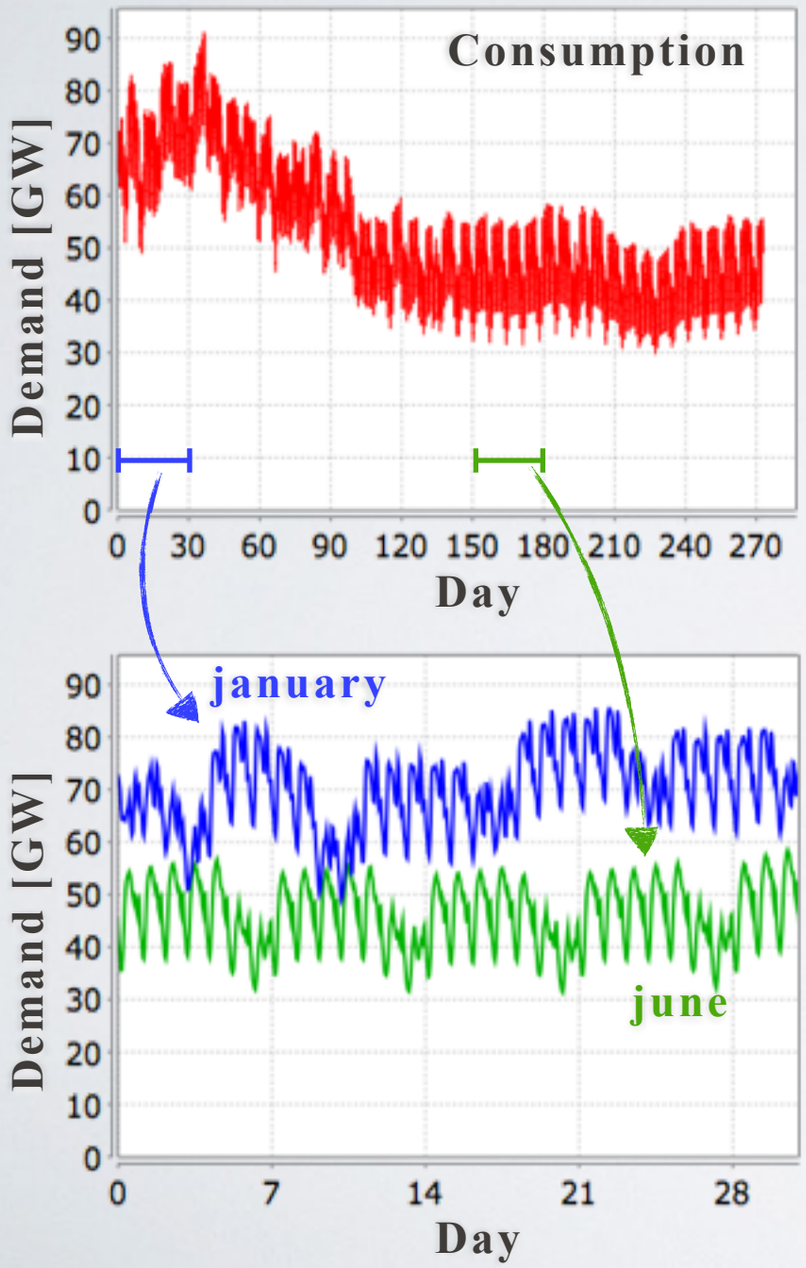

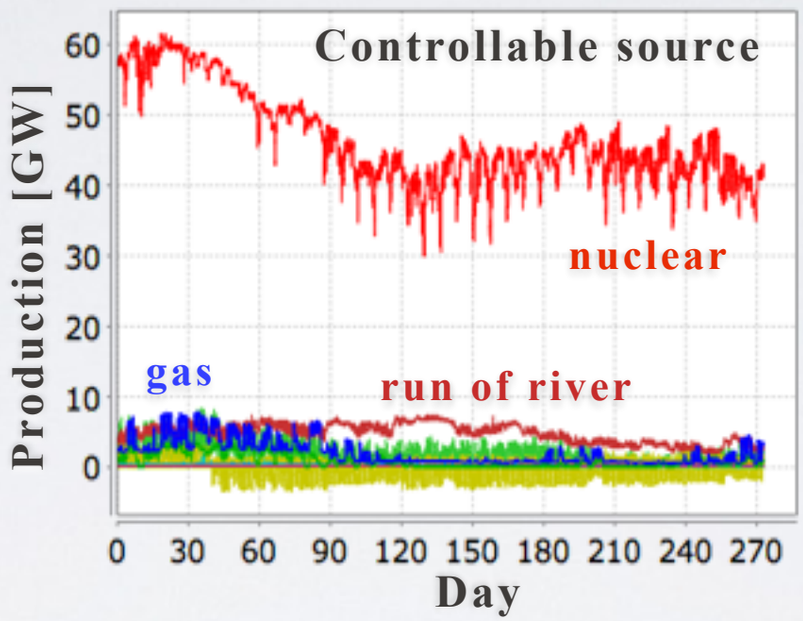

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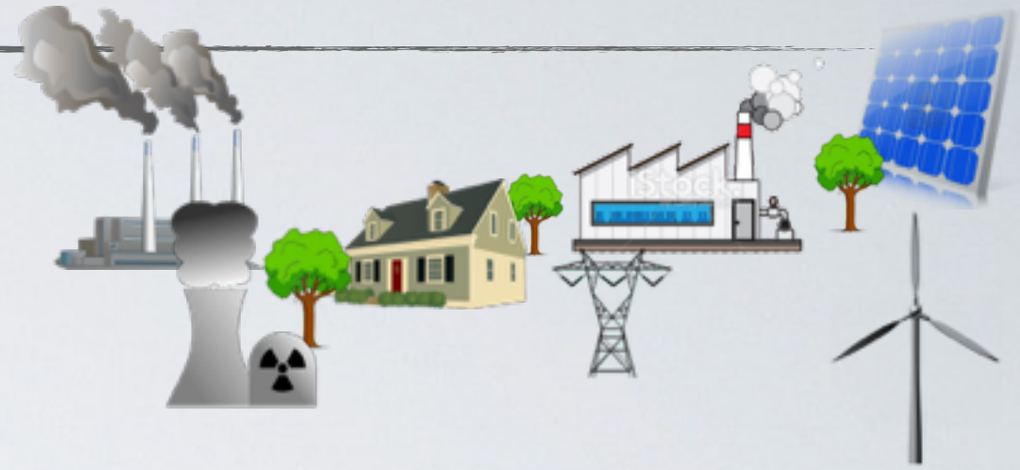

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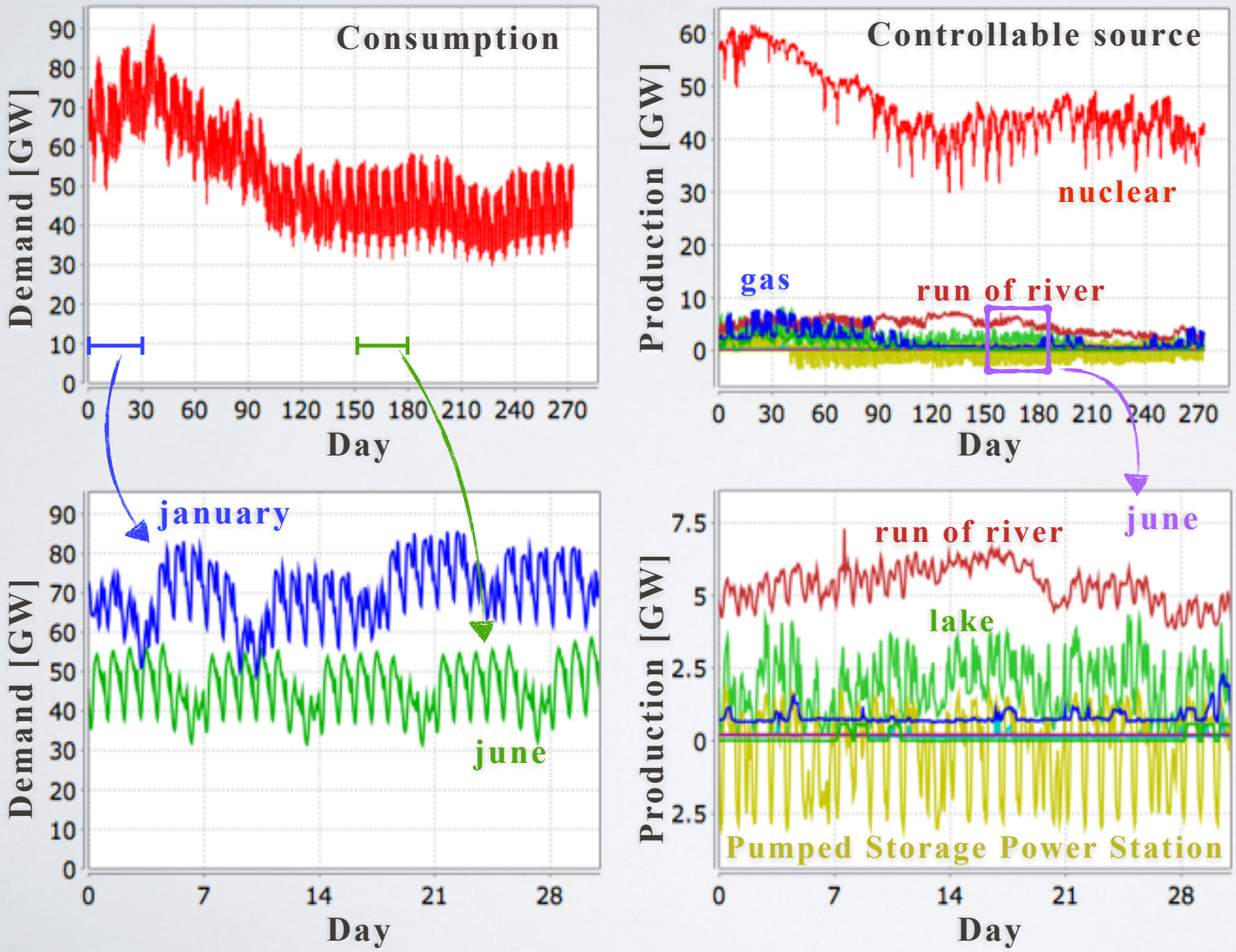

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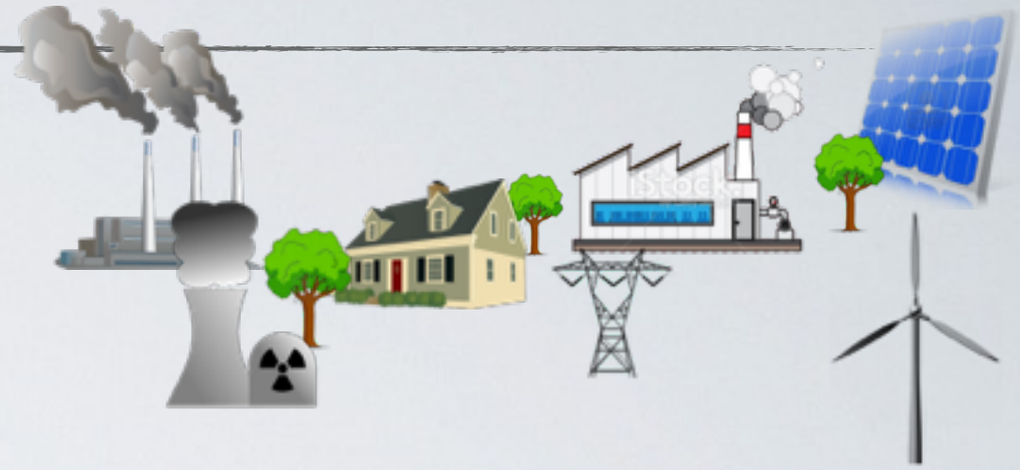

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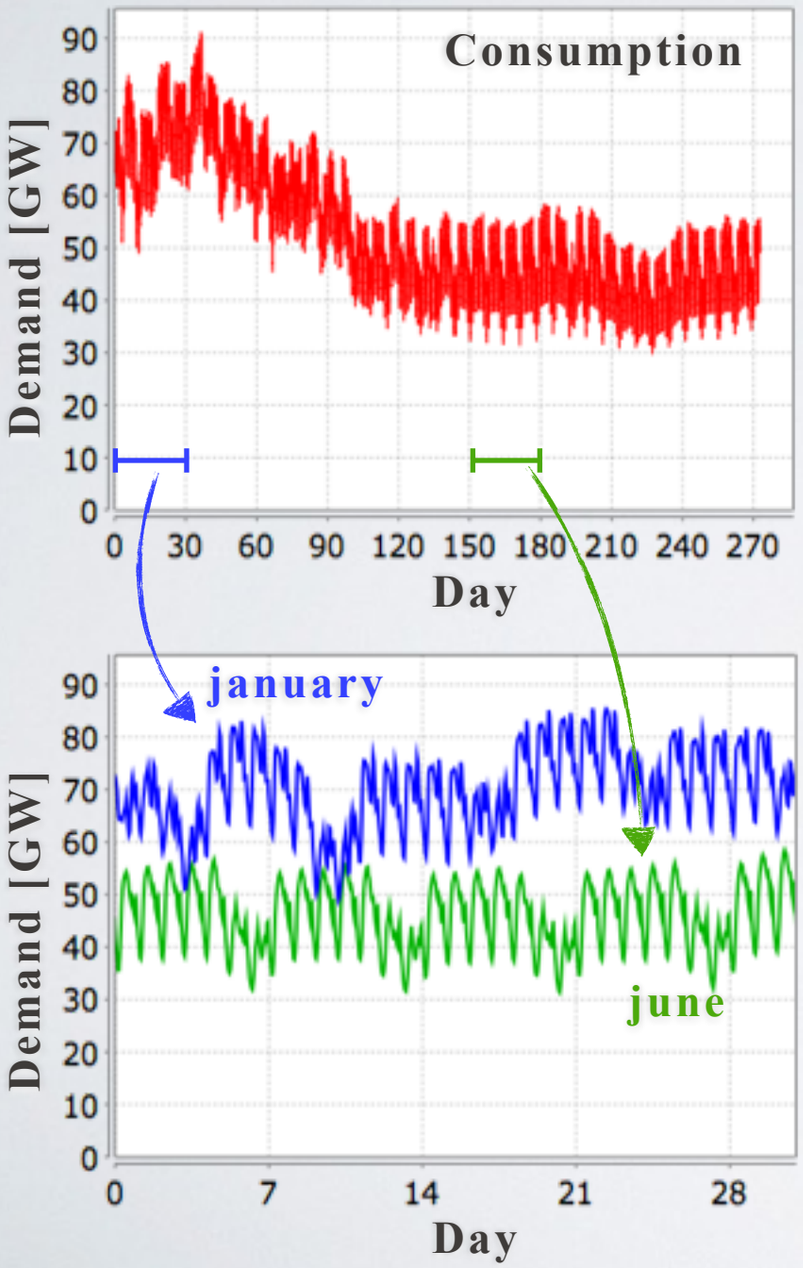

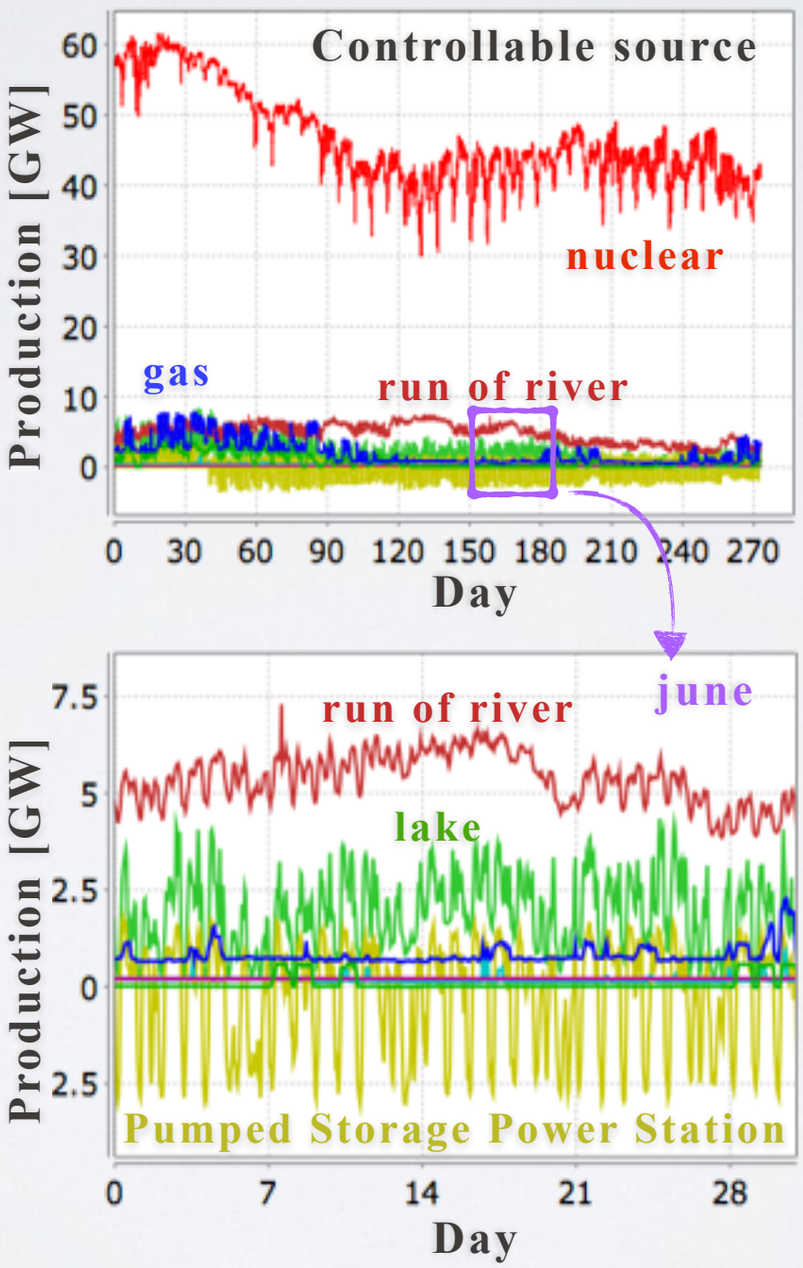

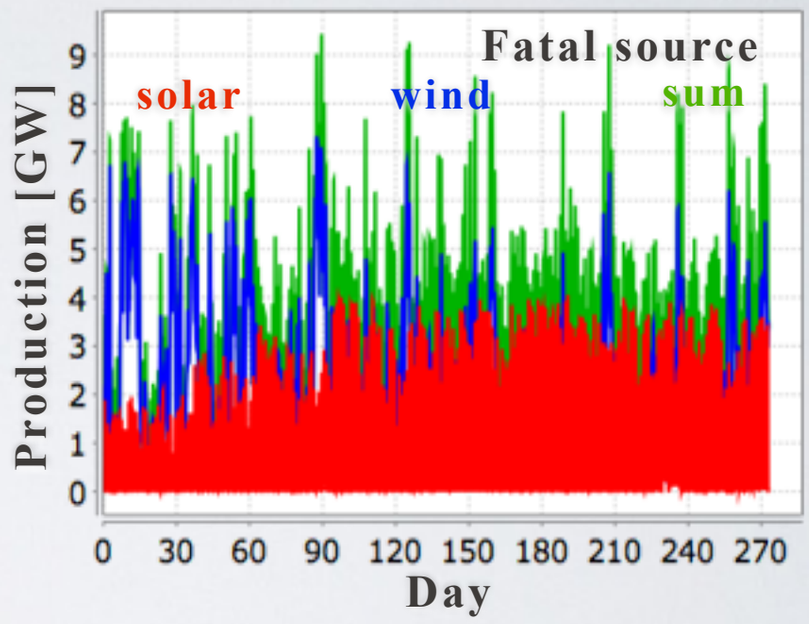

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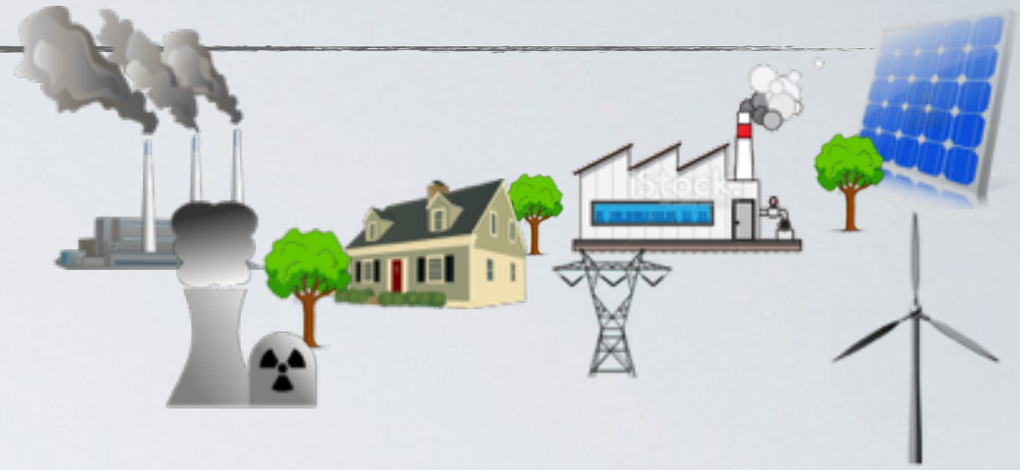

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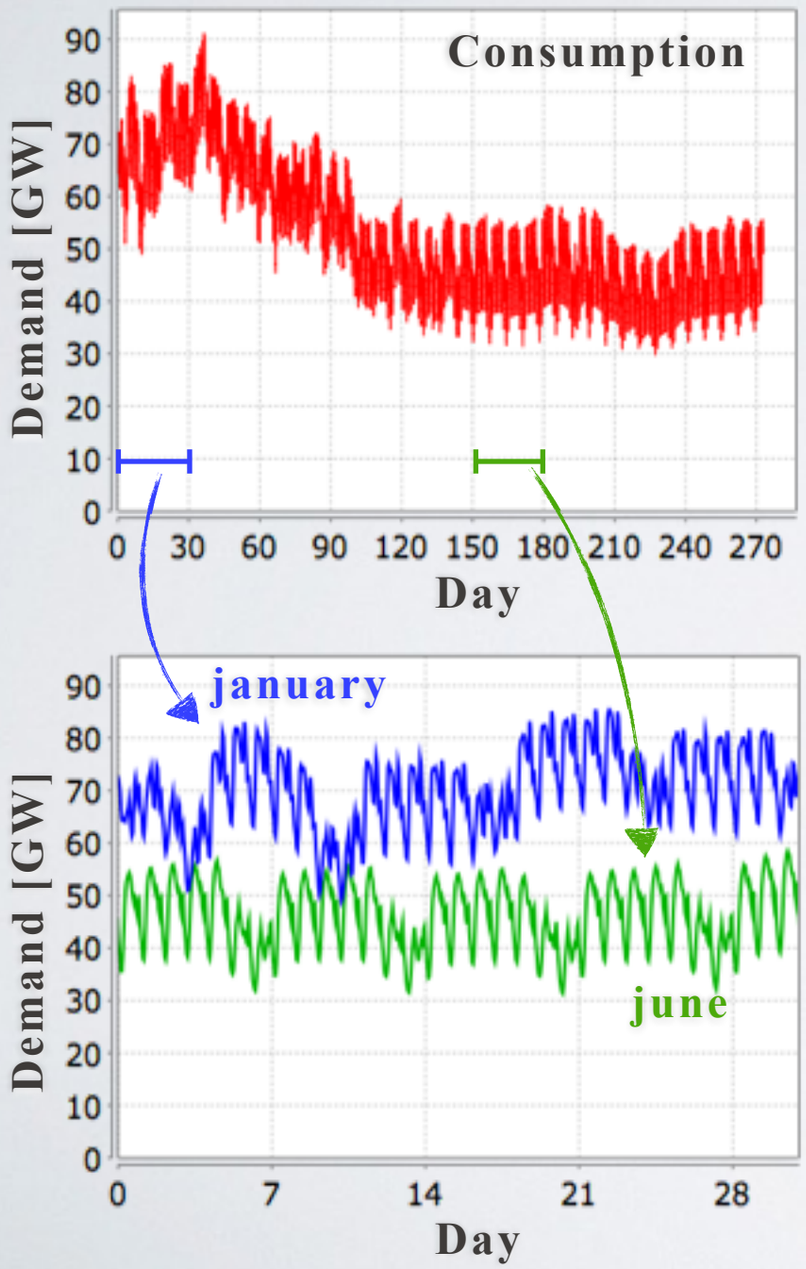

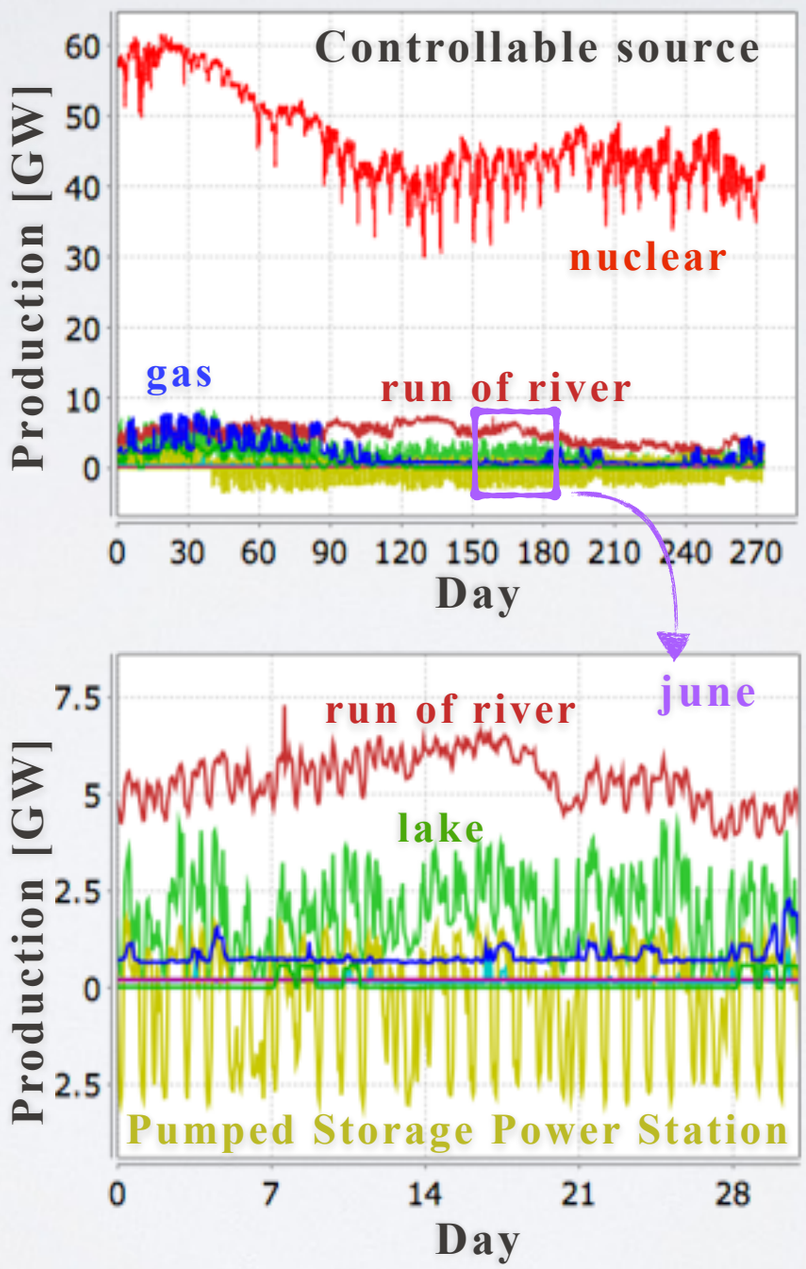

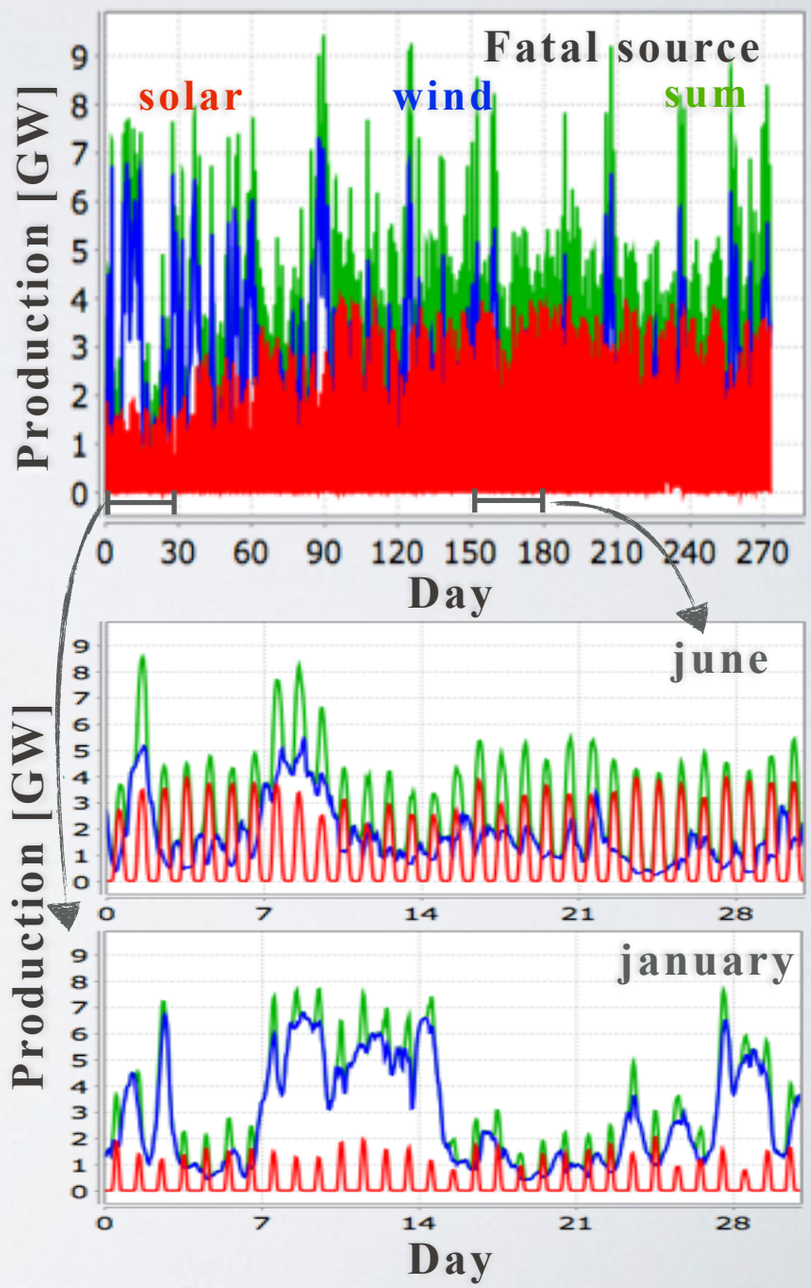

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ELECTRICITY MIX

Context:

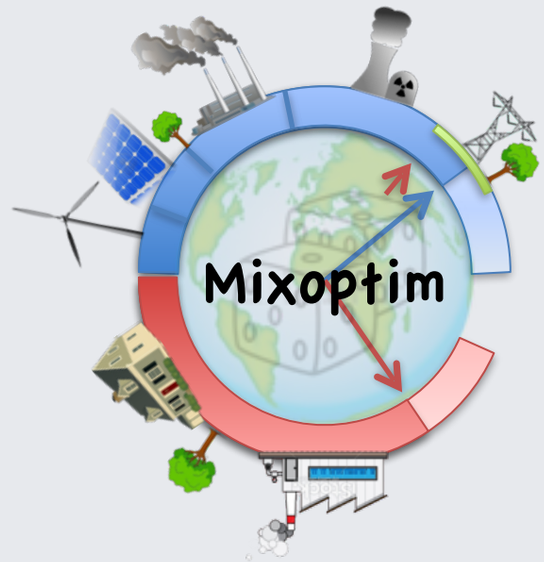
- the power demand must be satisfied
- different ways to produce energy

Ongoing studies:

- increasing renewable part in the mix!
- fatal production complex to model
- the production of conventional sources depends on the availability of other sources

k_d —(???)→ k_p

availability factor → load factor



- usually, the k_p values are assumed…

how can we make a simple tool able to take into account the expansion of the fatal sources and the interactions between sources?

[B. Bonin, H. Safa, A. Laureau, E. Merle-Lucotte, J. Miss, Y. Richet, MIXOPTIM: a tool for the evaluation and the optimization of the electricity mix in a territory, *Eur. Phys. J. Plus, 129, 198,2014]*

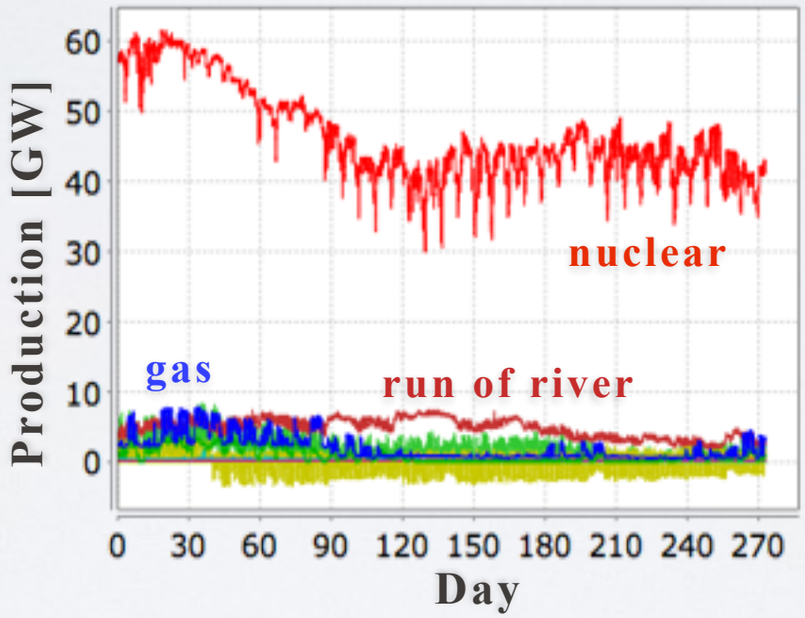
[source : RTE]

MIXOPTIM - GENERAL APPROACH

Objective:

- predict the behavior of a non-existing electricity mix …
- … using an existing mix

*The **production** chronicles reflect past events, changing one source production affect the others…*



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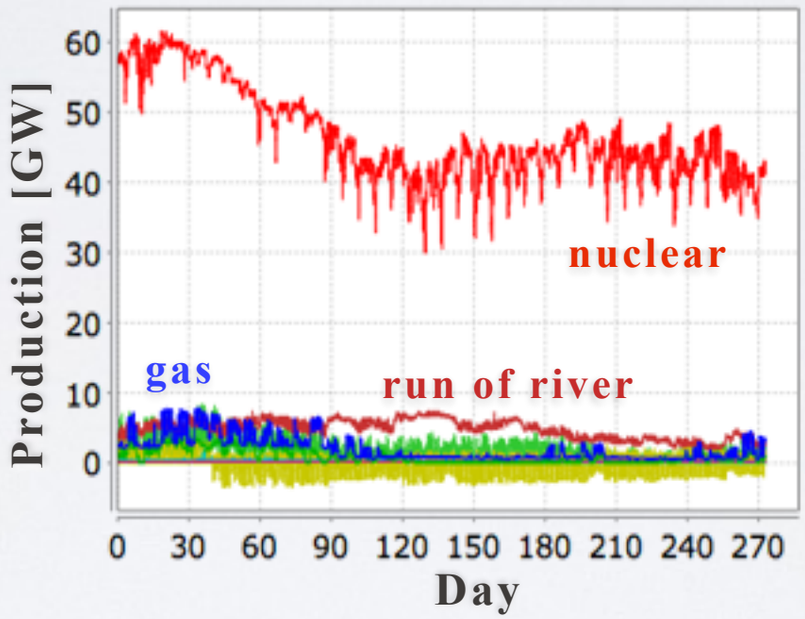
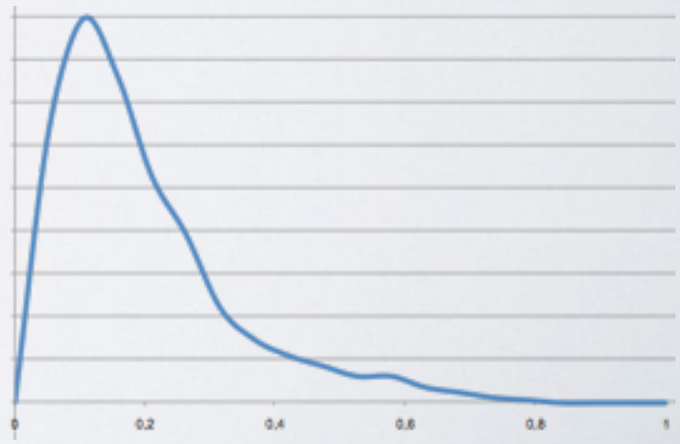
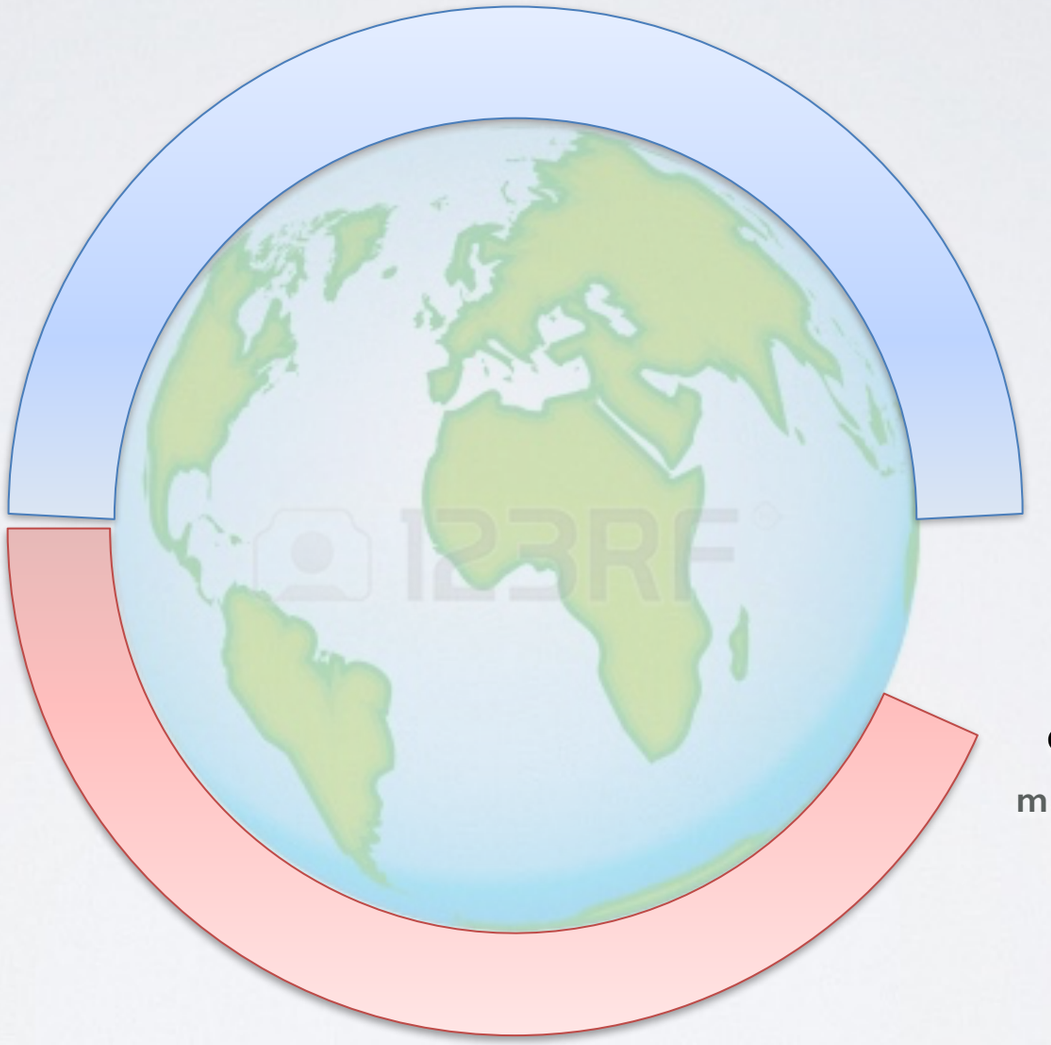


… *while the **availability** chronicles are almost an intrinsinc charateristic of the sources*



Wind availability law

MIXOPTIM - General approach



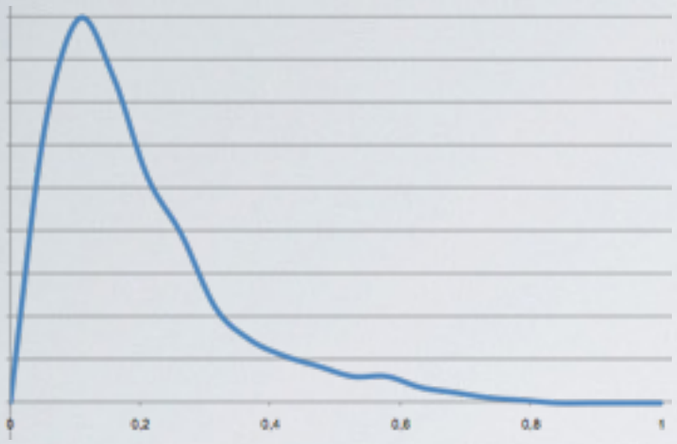
production

max: 130 GW

demand

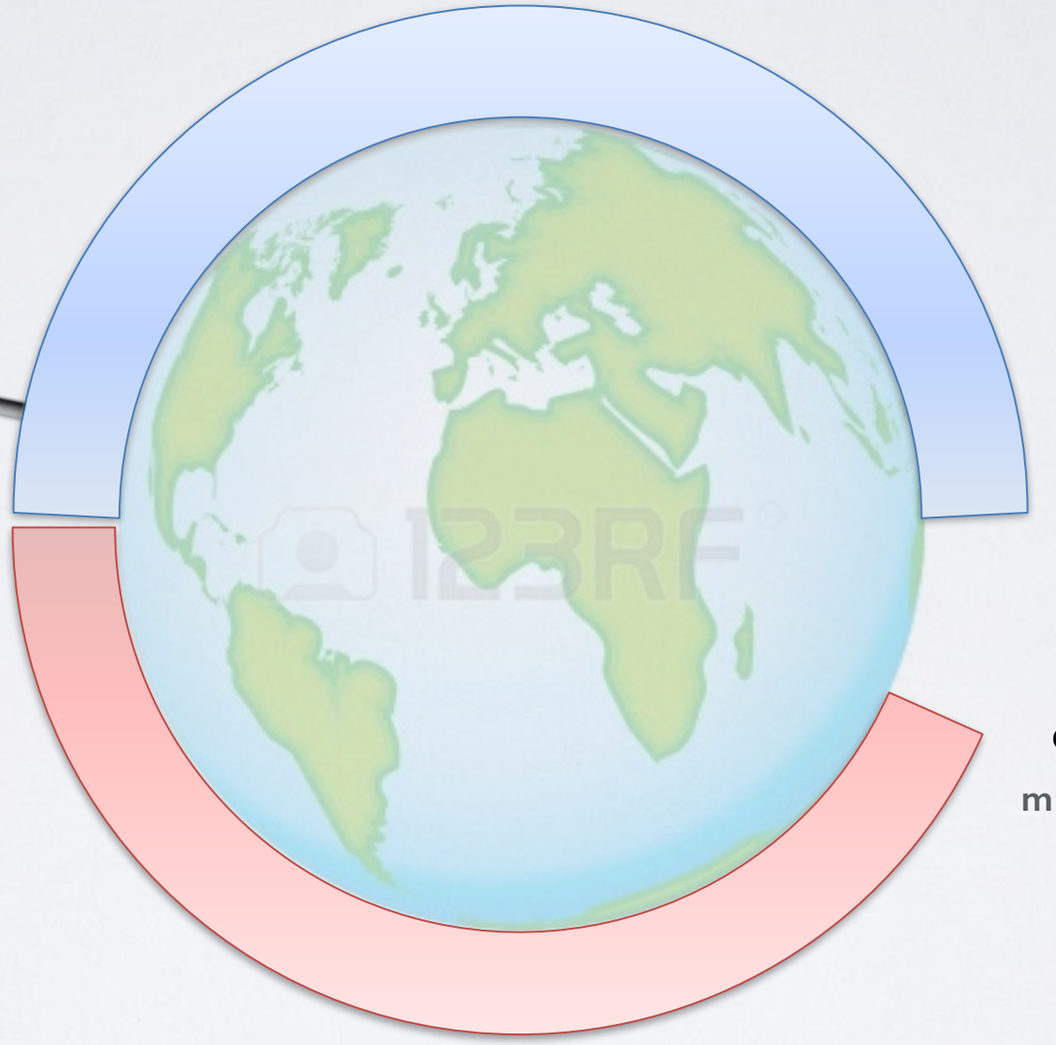
max: 100 GW

MIXOPTIM - GENERAL APPROACH



Wind probablity law

10 GW installed



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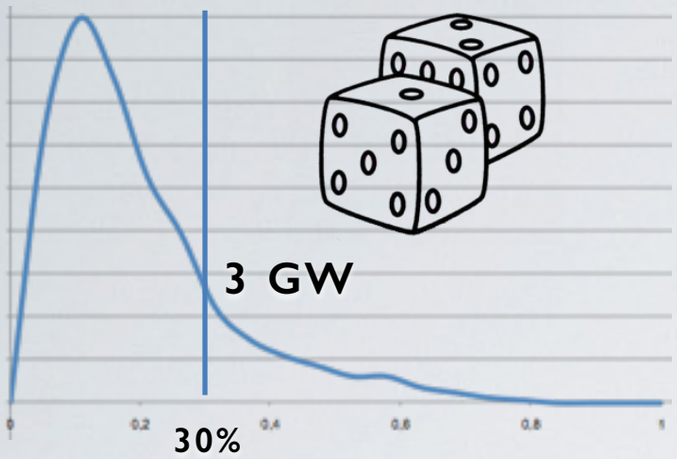

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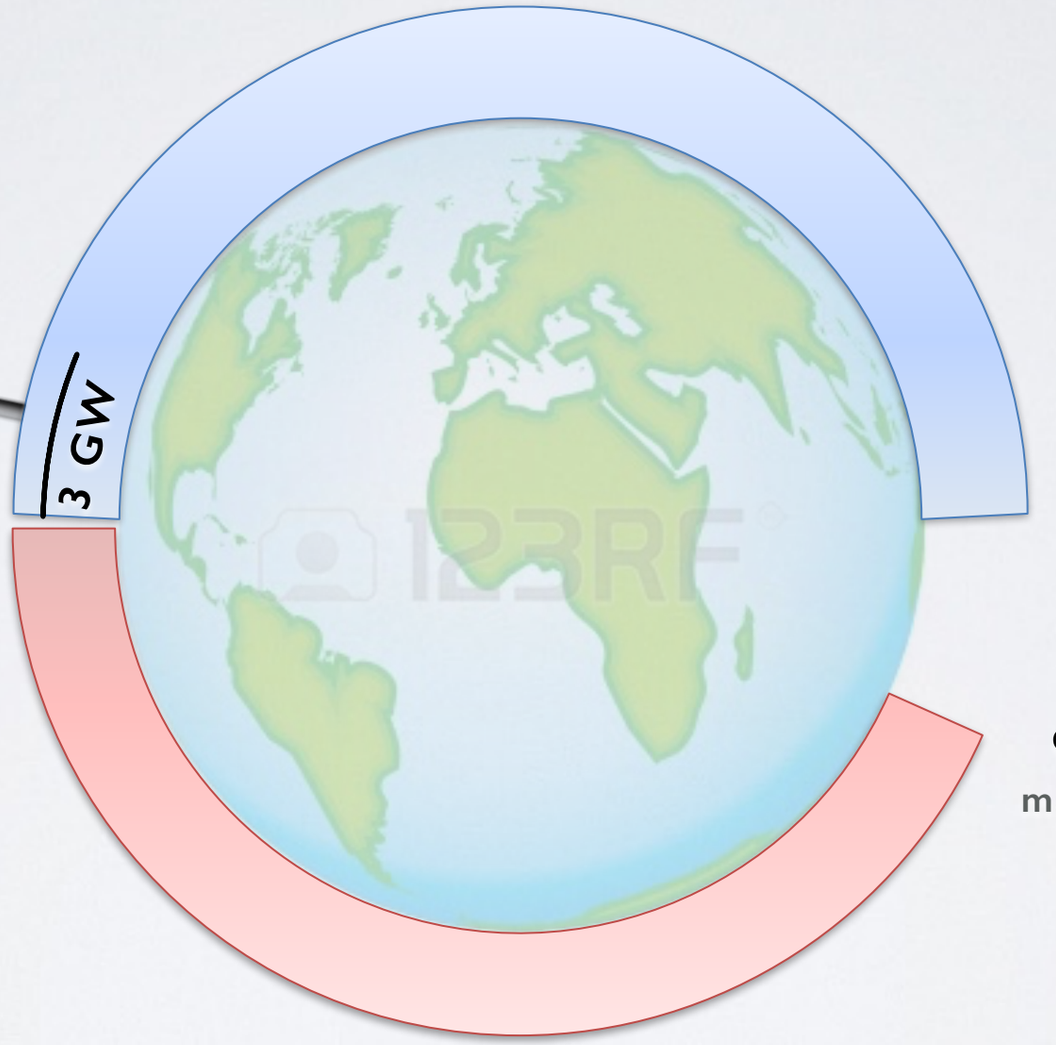

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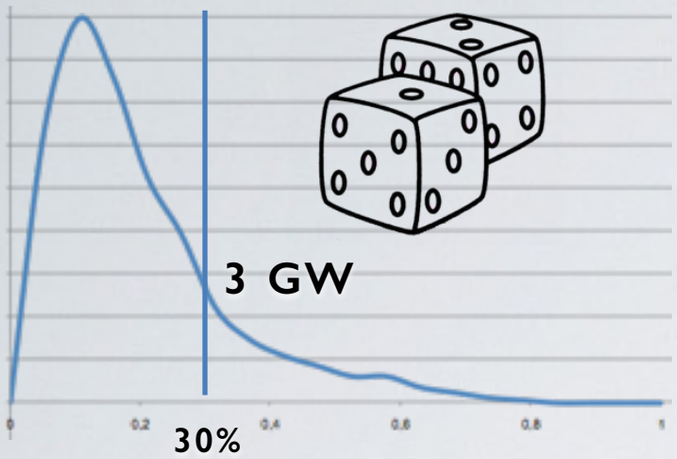

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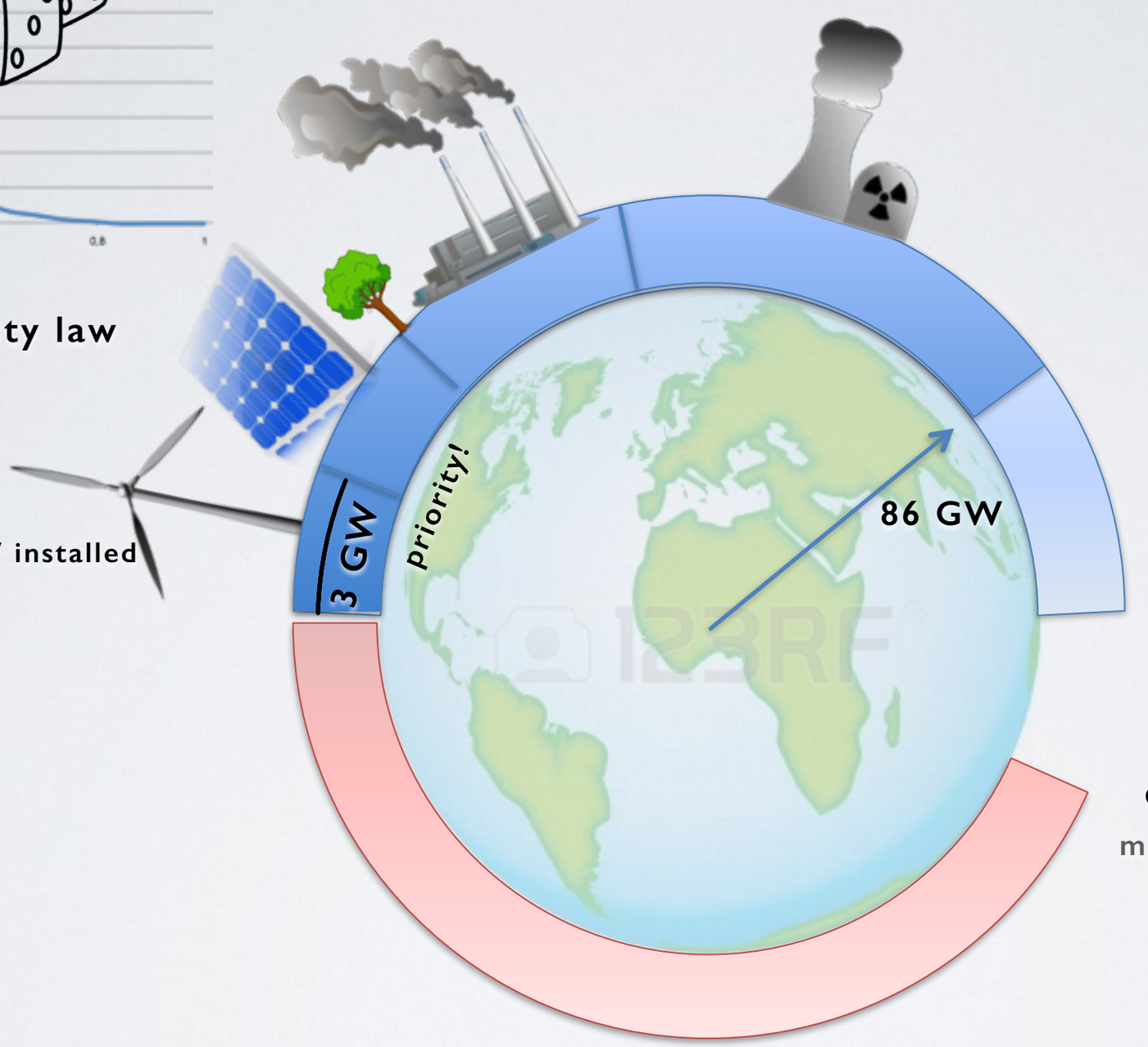

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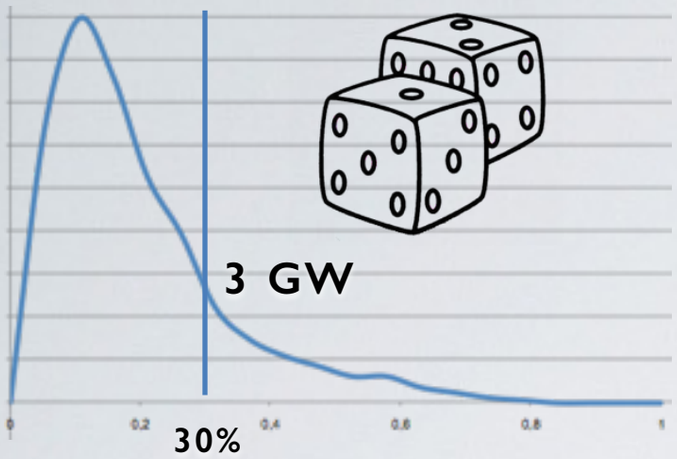

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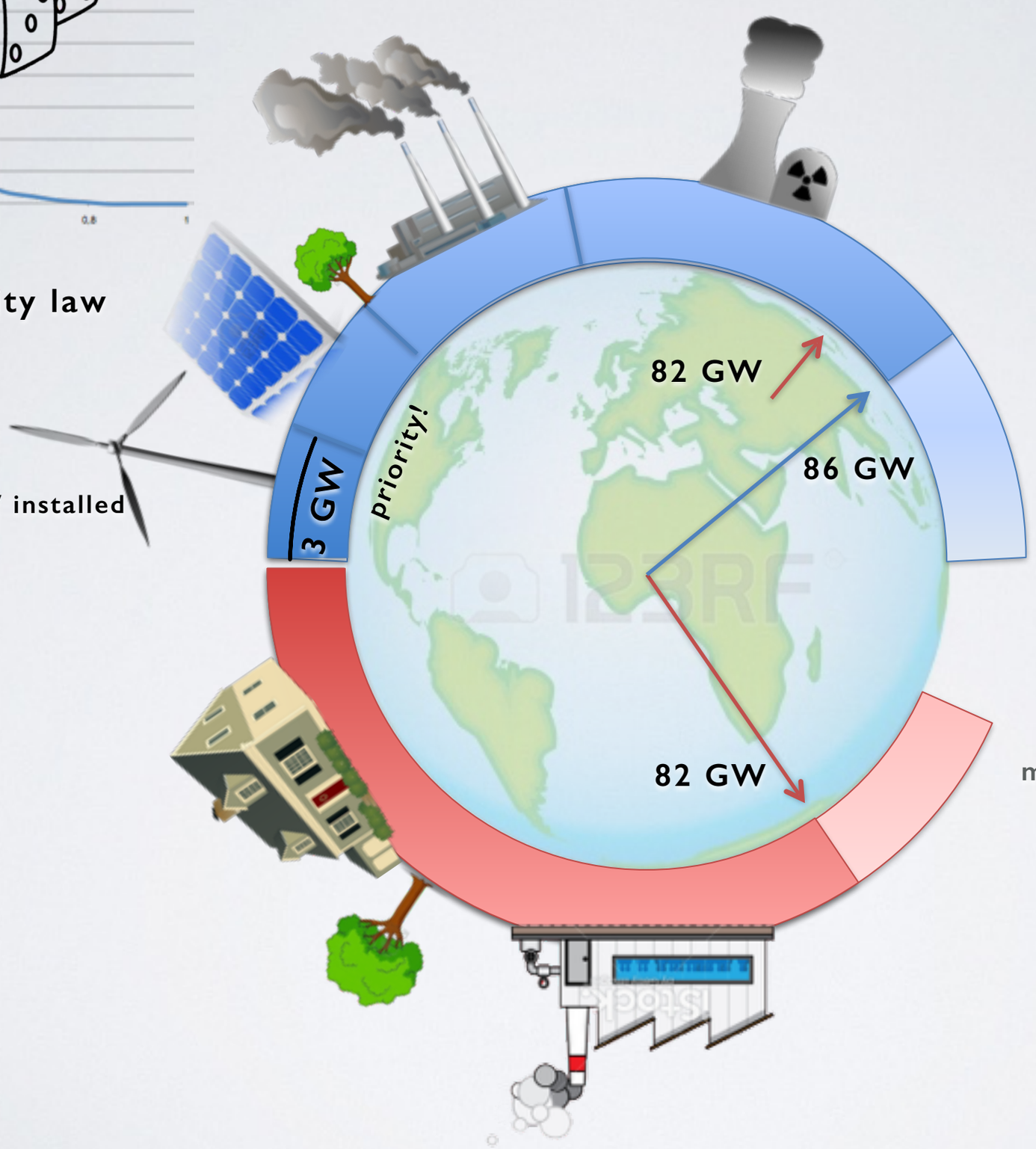

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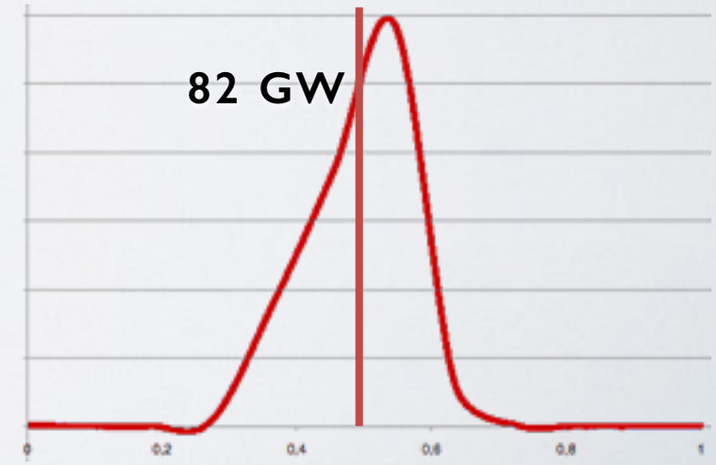
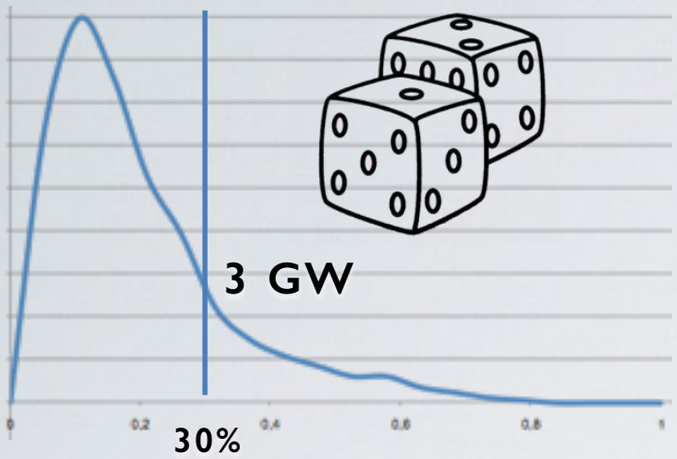


Consumption probablity law

MIXOPTIM - GENERAL APPROACH



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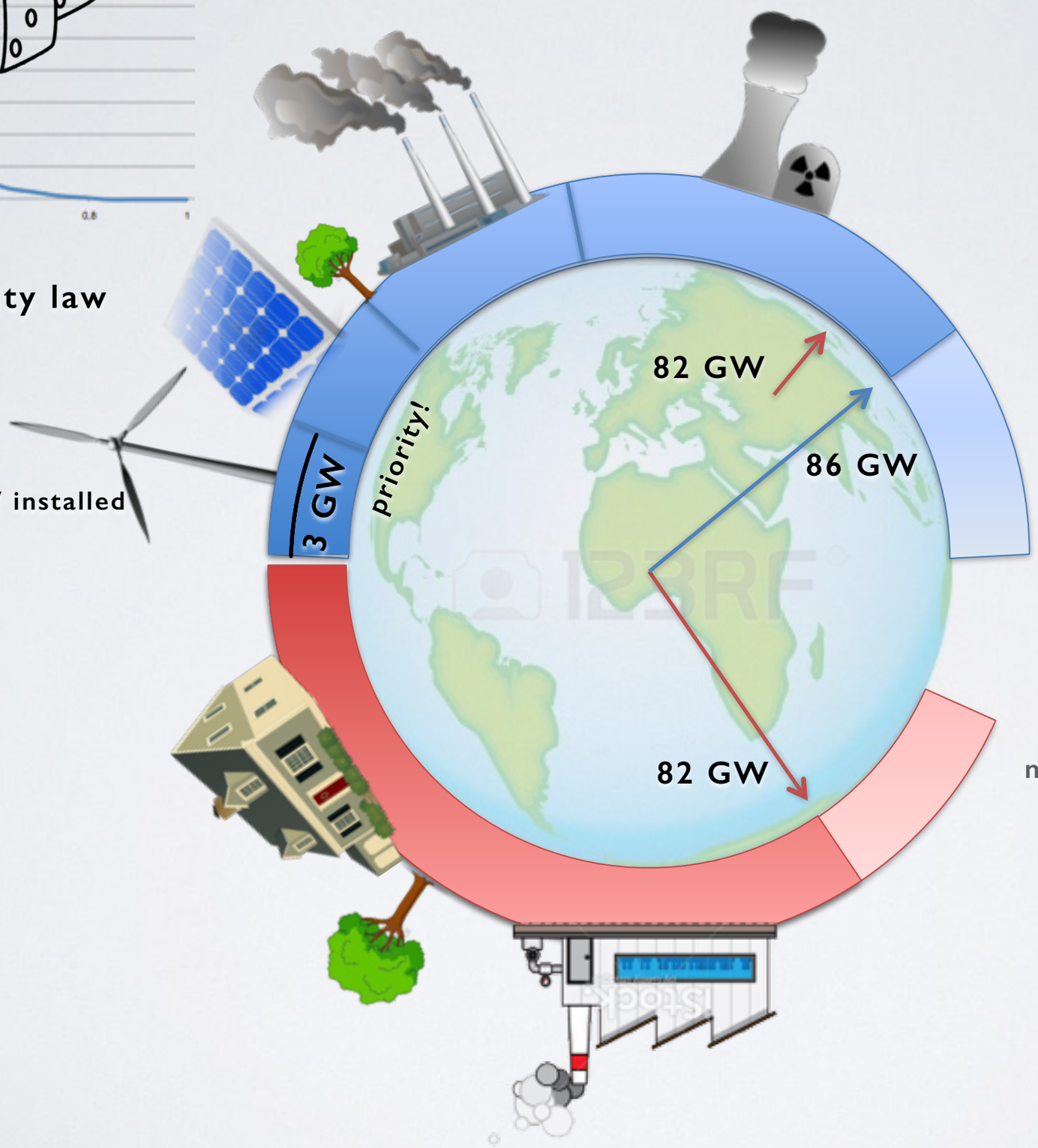

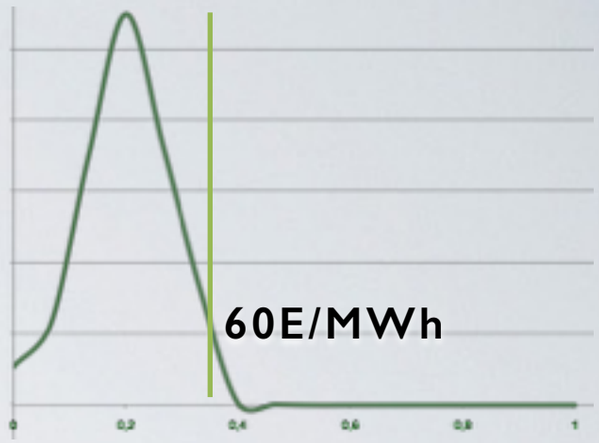

Interconnection cost probablity law

production

max: 130 GW

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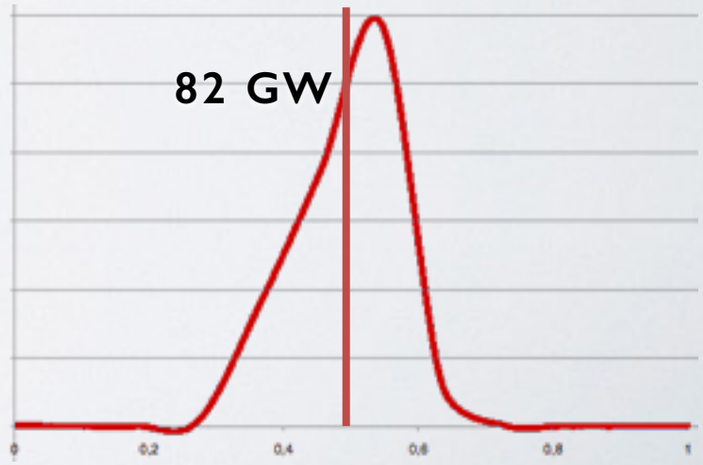

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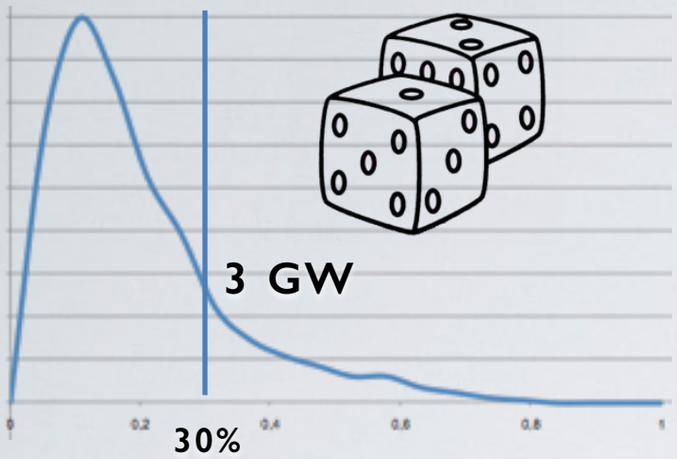
MIXOPTIM - General approach



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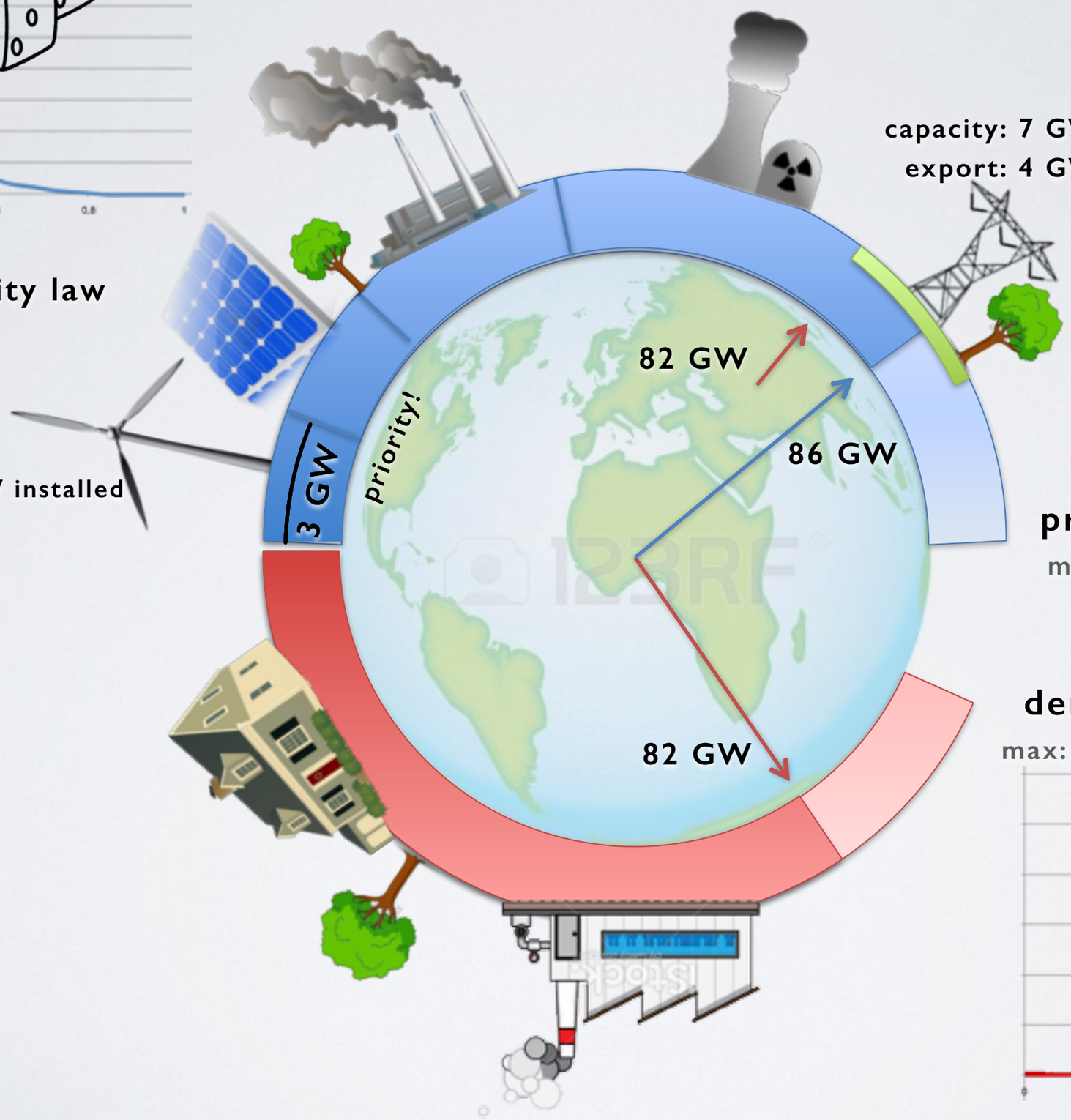

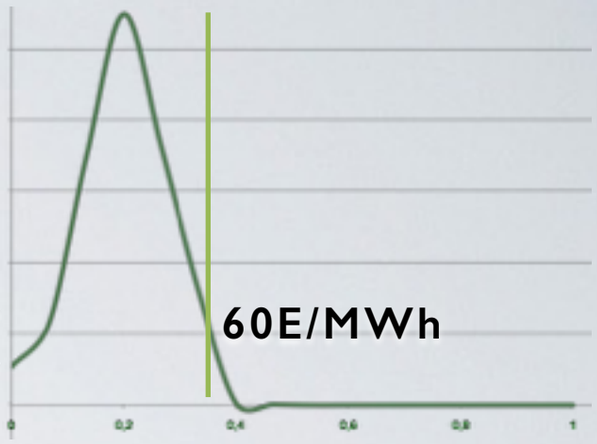

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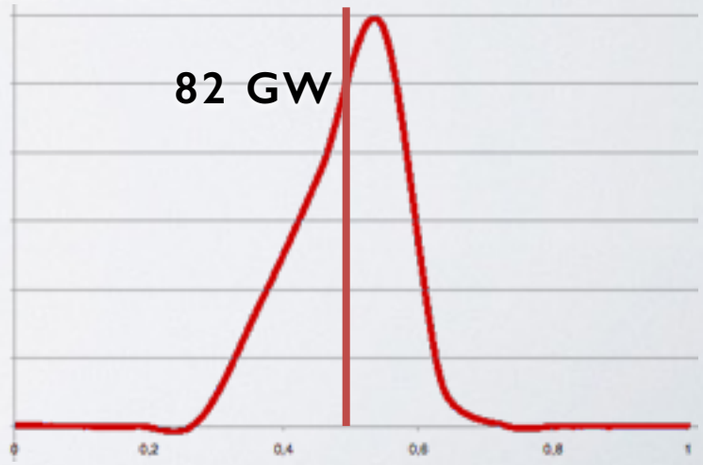

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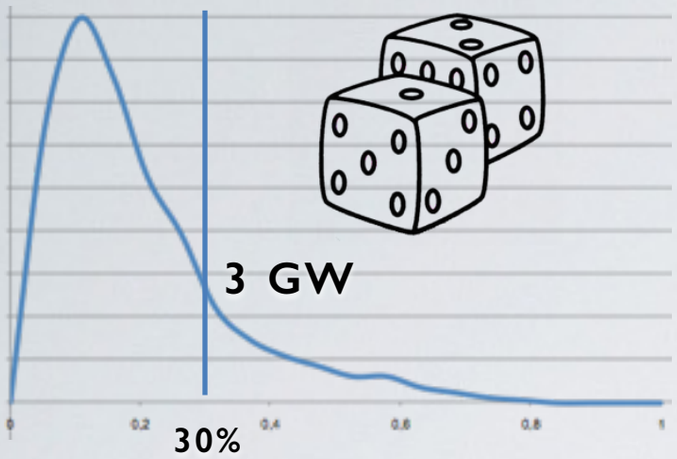

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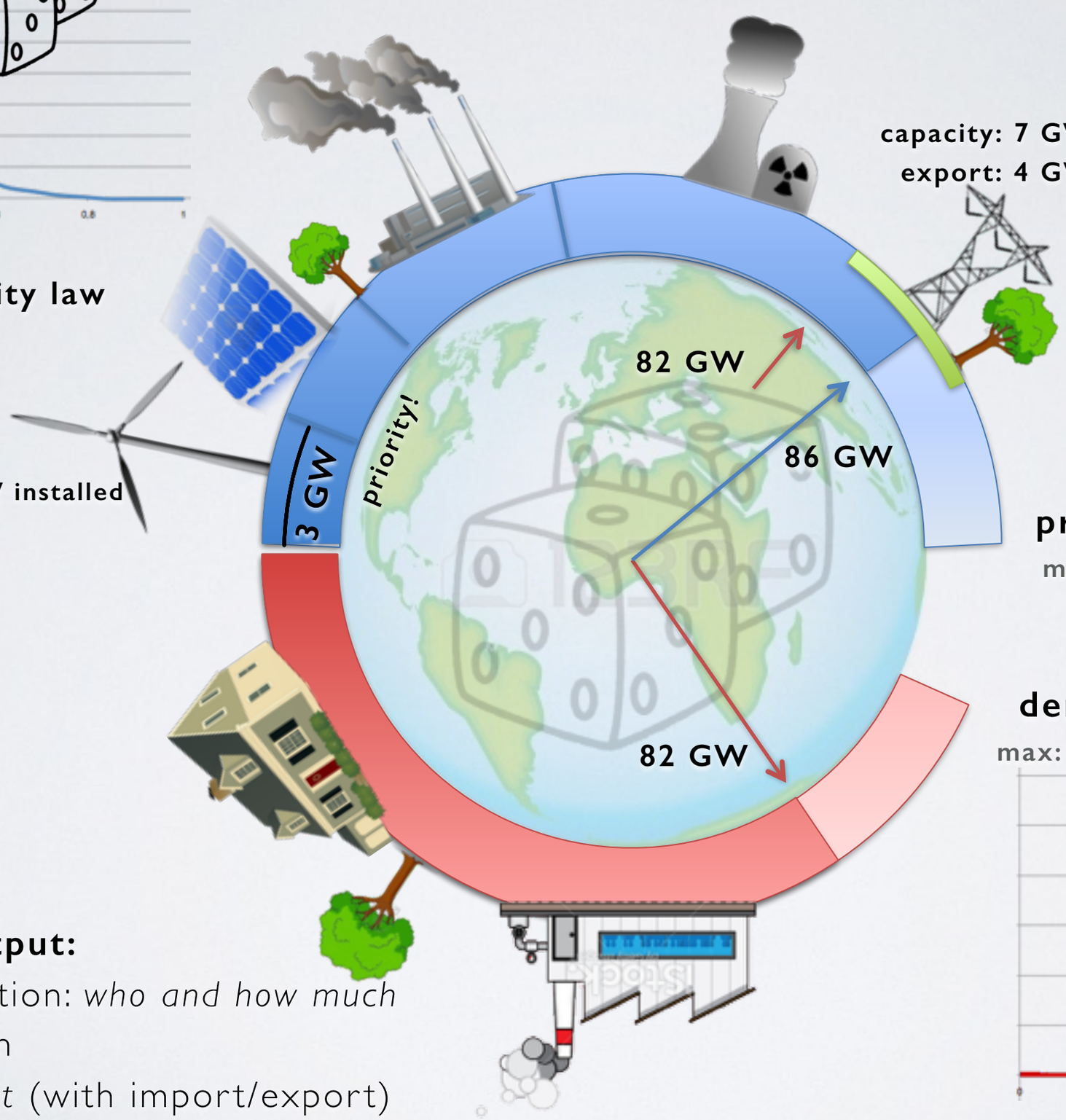
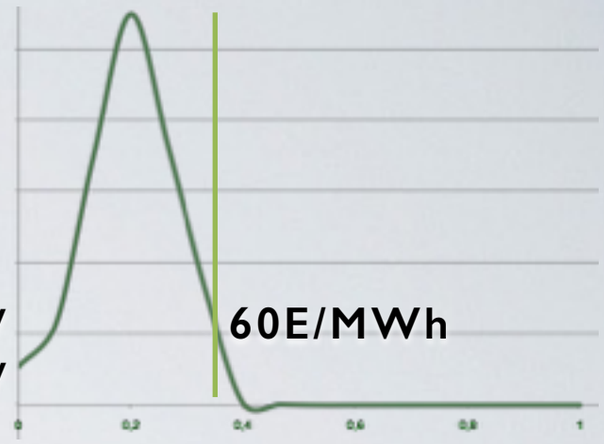


capacity: 7 GW
export: 4 GW



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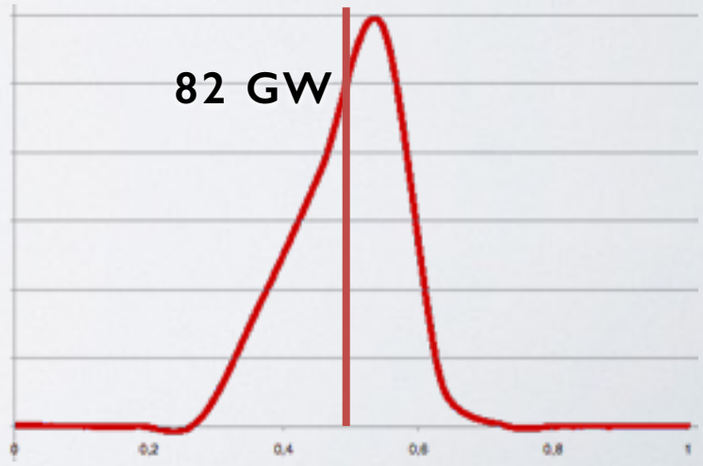


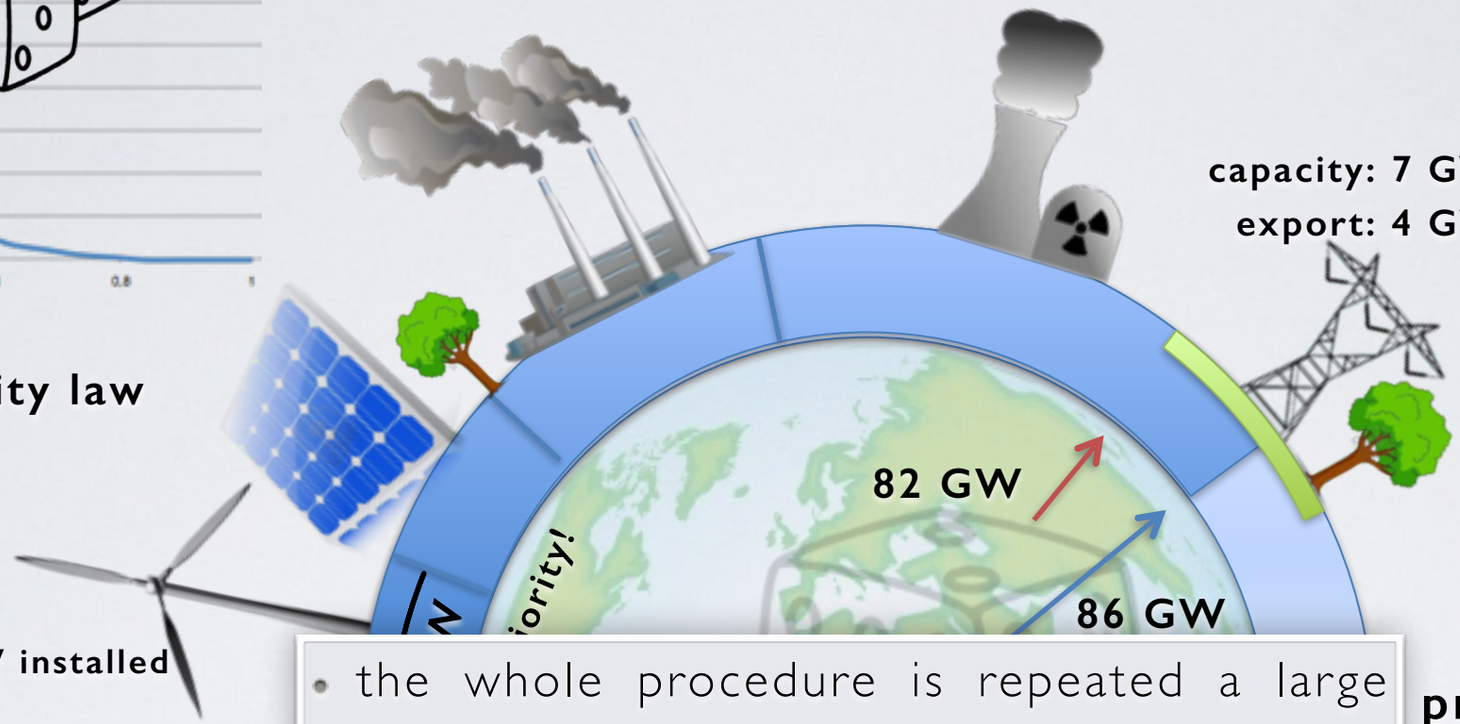
Consumption probablity law

Calculation output:

- energy production: *who and how much*
- CO_2 production
- production *cost* (with import/export)
- ability to support (or not) the demand

MIXOPTIM - GENERAL APPROACH

Wind probablity law



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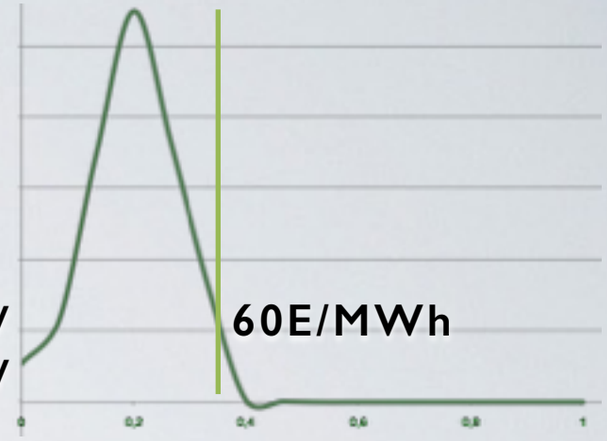

capacity: 7 GW
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Interconnection cost probablity law

- the whole procedure is repeated a large number of times…
- … and an average behavior is estimated

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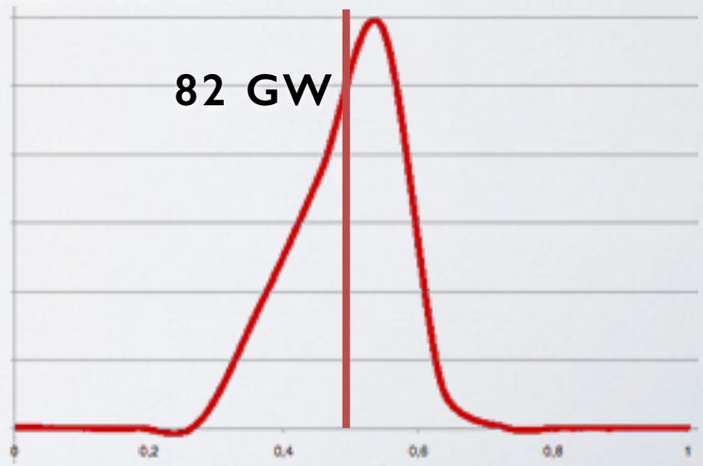
demand

max: 100 GW



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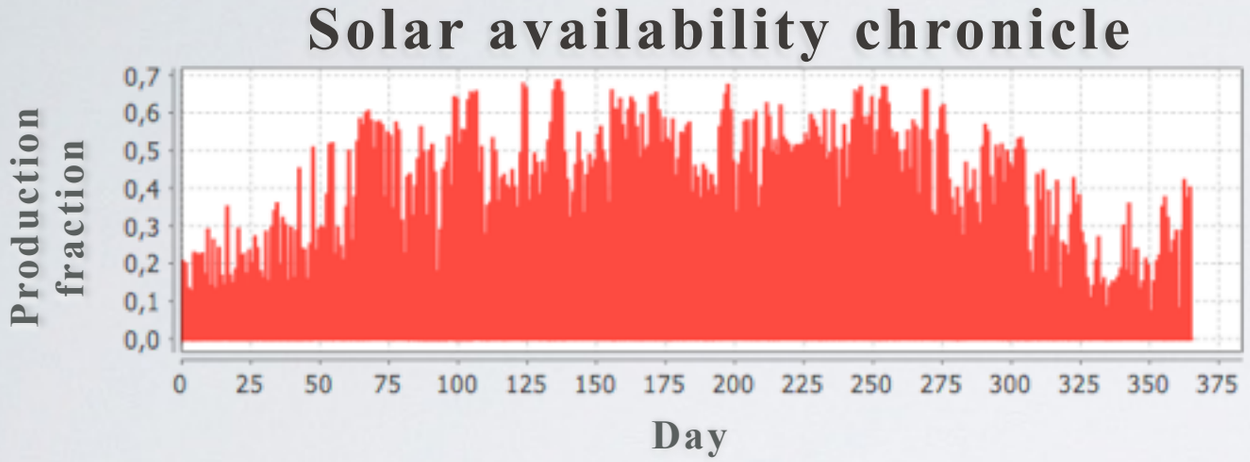
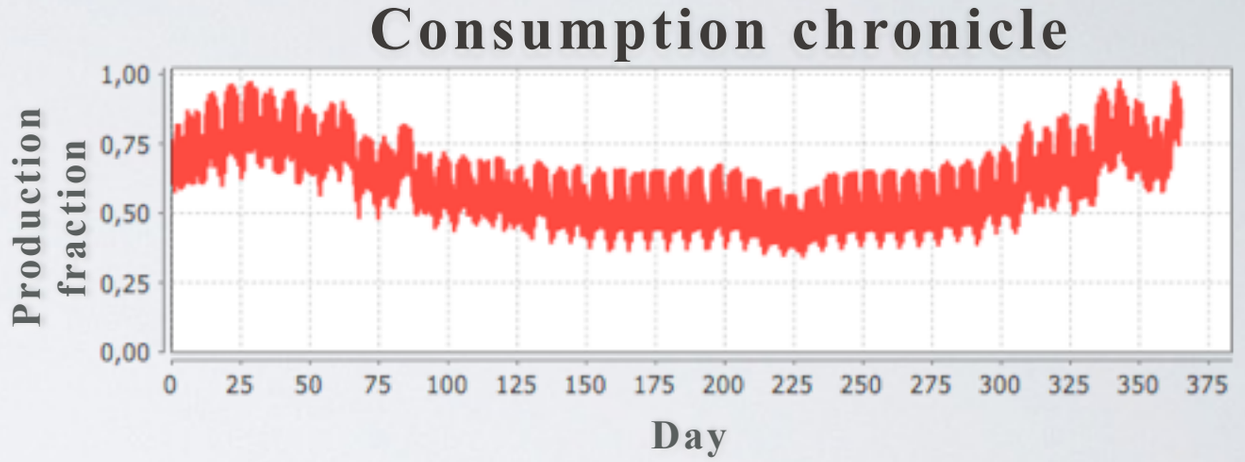
MIXOPTIM - GENERAL APPROACH

Two aspects modeled:

- Availability law
- Spectral analysis





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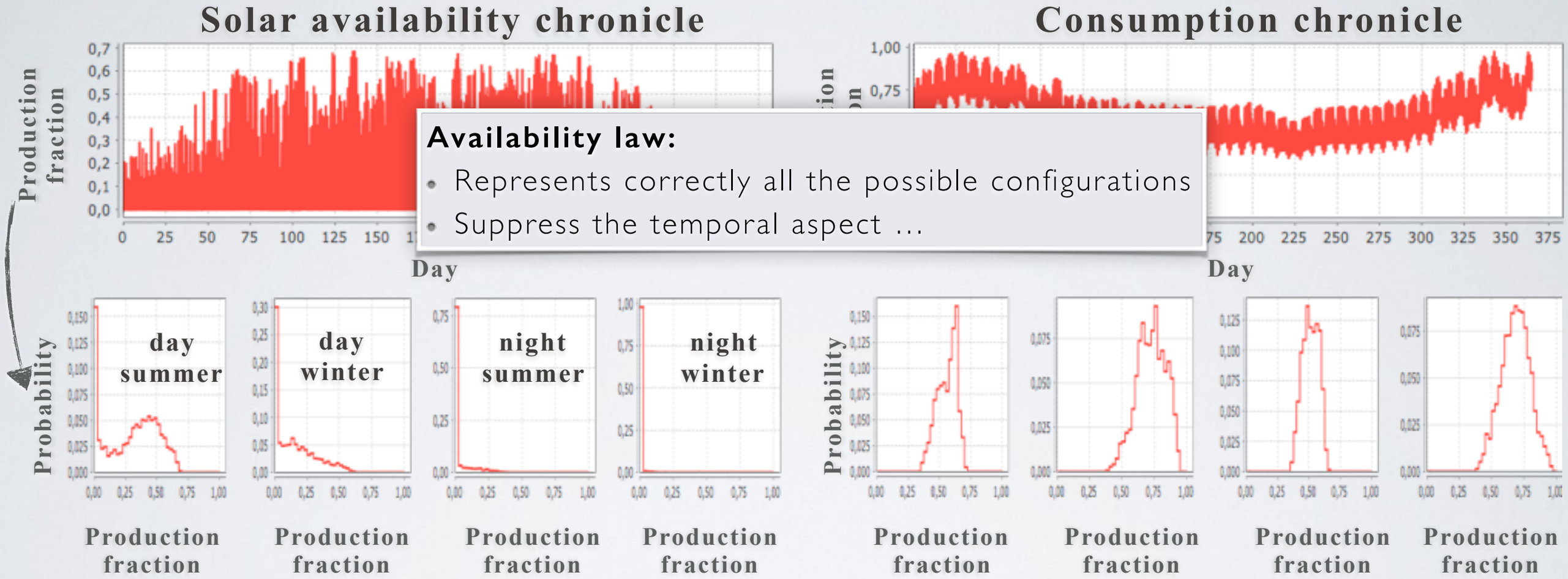

Availability law:

- Represents correctly all the possible configurations
- Suppress the temporal aspect …

MIXOPTIM - GENERAL APPROACH

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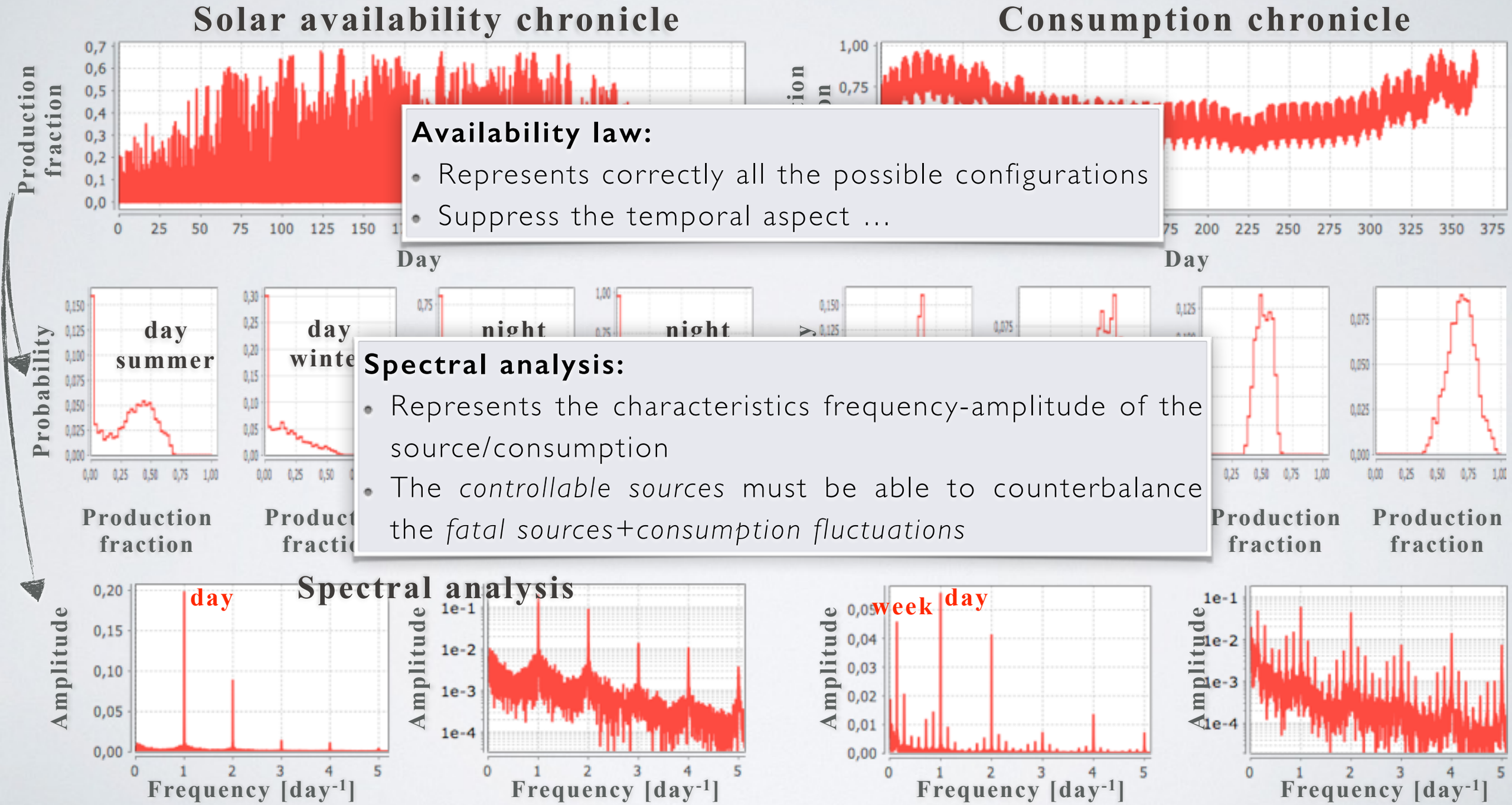
- Availability law
- Spectral analysis



Availability law:

- Represents correctly all the possible configurations
- Suppress the temporal aspect …

Spectral analysis:

- Represents the characteristics frequency-amplitude of the source/consumption
- The *controllable sources* must be able to counterbalance the *fatal sources+consumption fluctuations*

Input file using xml format:

```
(...)
<pwr
   marginal_cost="10."
   fixed_cost="12."
   marginal_co2="0."
   fixed_co2="1.5e-3"
   priority_order="4"
   power="63130."
   alias_availability_law="pwr_law"/>
(...)
<pwr_law>
   <chronicle path="data/raw/pwr_data" nb_bin_per_day="48" nb_bin_in_law="100"/>
   <loi_1   val="0 0 0 0 0 0 0 0 0 0 0 0.11 0.22 1.22 8.80 9.80 0 0 0 0"/>
   <loi_2   val="0 0 0 0 0 0 0 0 0 0 0 0 0 0.88 1.60 1.86 2.60 5.60 4.60 2.54"/>
   <loi_3   val="0 0 0 0 0 0 0 0 0 0 0 0 0.11 0.22 1.22 8.80 9.80 0 0 0 0"/>
   <loi_4   val="0 0 0 0 0 0 0 0 0 0 0 0 0 0.88 1.60 1.86 2.60 5.60 4.60 2.54"/>
</pwr_law>
(...)
```

direct calculation

or use given law

MIXOPTIM - MIX STUDY

Example of the French electricity mix

MIXOPTIM - IHM 7.4

new calculation...

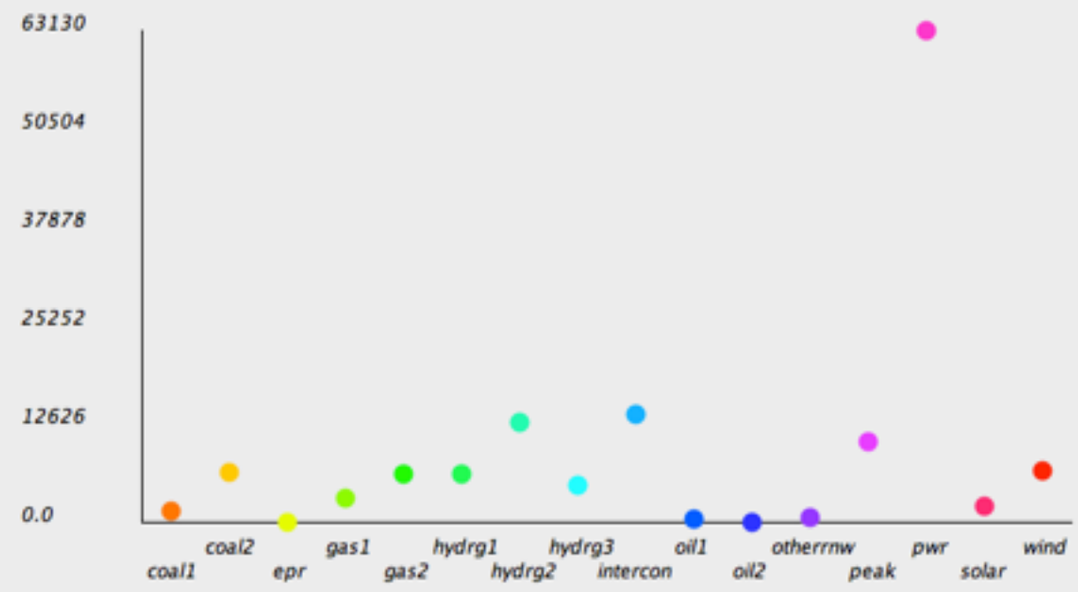
Introduction | manual | calculation | calculation | calculation | calculation

close tab | java simulation

sample number: 1 000 000 | start!

parc francais
park coal
park europe
park french
park french rwb stock
park french save
park gas

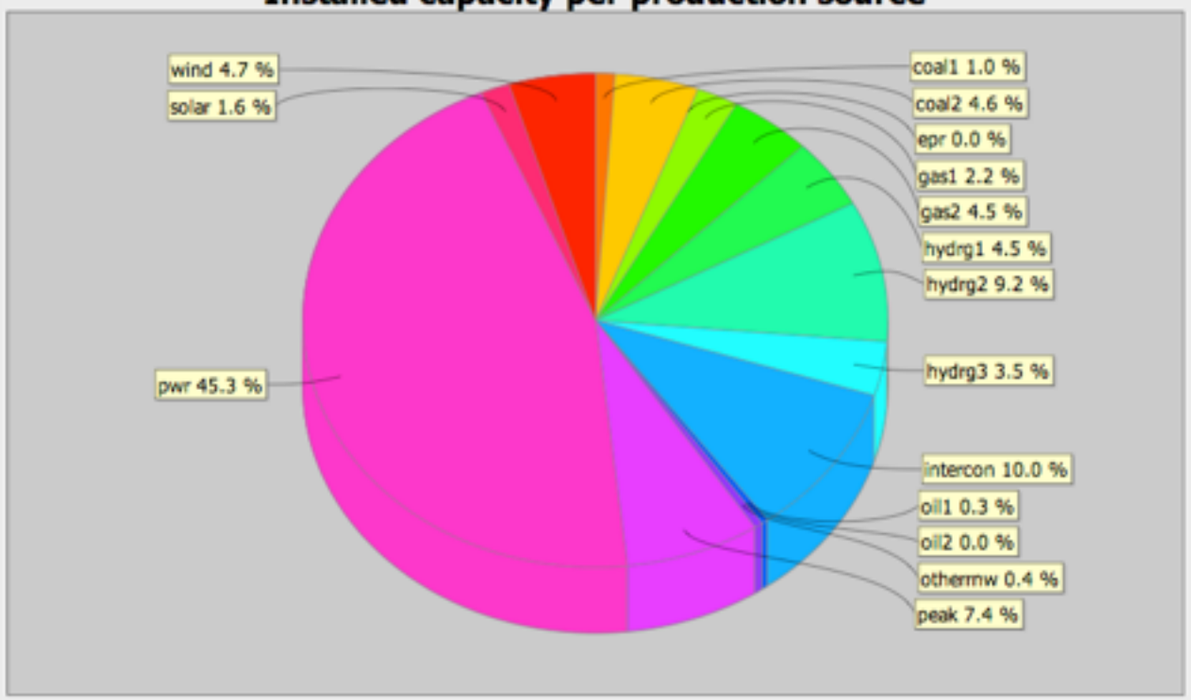
drag and drop to modify...



... or modify directly the value in the table below
(click on "enter" to validate the new value)

coal1	1500.
coal2	6440.
epr	0.
gas1	3200.
gas2	6290.
hydrg1	6390.
hydrg2	12900.
hydrg3	4940.
intercon	14000.
oil1	500.
oil2	0.
otherrnw	640.
peak	10360.
pwr	63130.
solar	2230.
wind	6640.
total	139160.0
demand	100000.0
taxe Euro...	0.0

Installed capacity per production source



MIXOPTIM - MIX STUDY

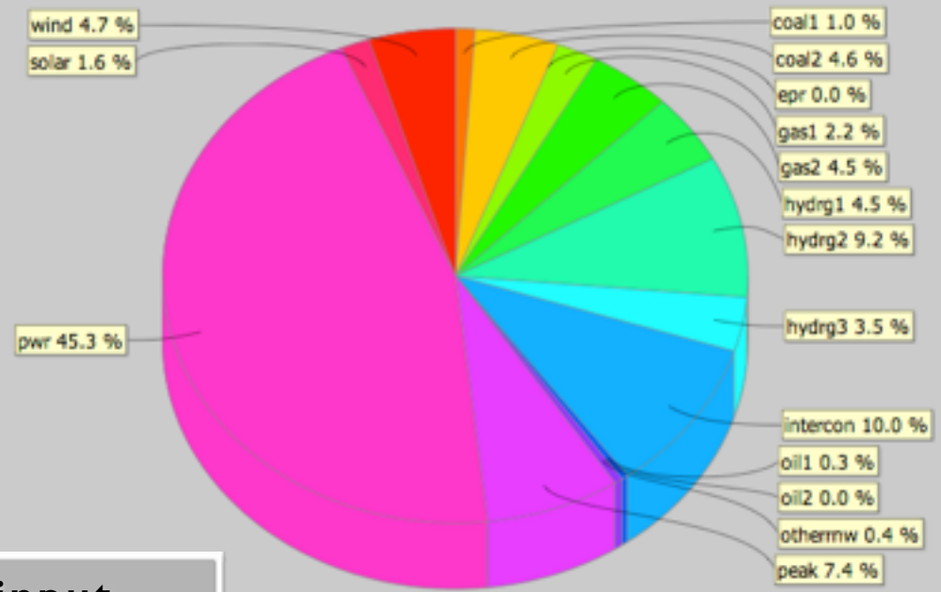
Example of the French electricity mix

MIXOPTIM - IHM 7.4

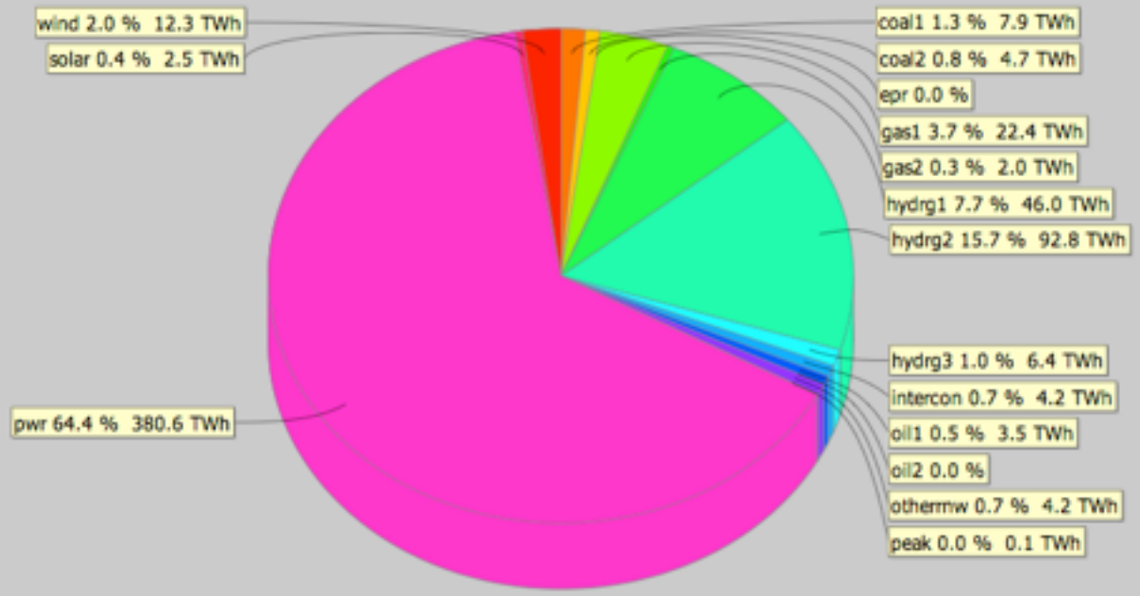
new calculation...

Introduction | manual | calculation | calculation | calculation | calculation

Installed capacity

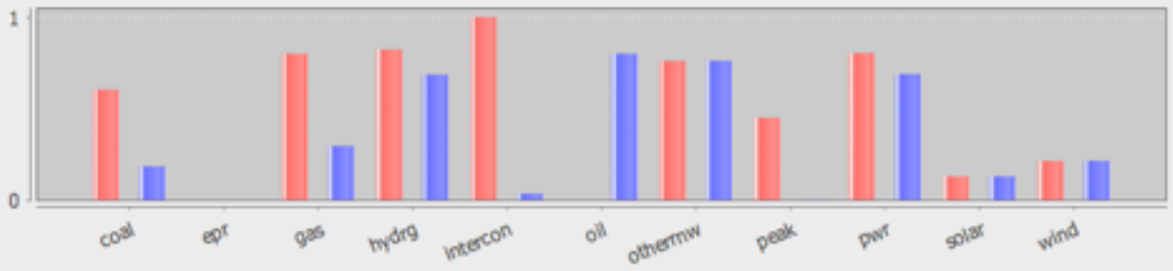


Actual production



input

Condensed availability and capacity factors



modify the mix | register the mix | close tab

```
10 millions of samples
average production cost    37.172 euros/MWh     sigma = 0.00494 %
average demand cost        45.768 euros/MWh     sigma = 0.00565 %
export (gross)             11.23 euros/MWh      sigma = 0.0207 %
average CO2                0.06276 ton/MWh      sigma = 0.0108 %
average produced power     67379 MW             sigma = 0.00512 %
average demanded power     54723 MW             sigma = 0.00716 %
load shedding              2.4E-4 %             sigma = 22.0 %
export                     23.12 %              sigma = 0.0144 %
import                     0.872 %              sigma = 0.16 %
```

MIXOPTIM - MIX STUDY

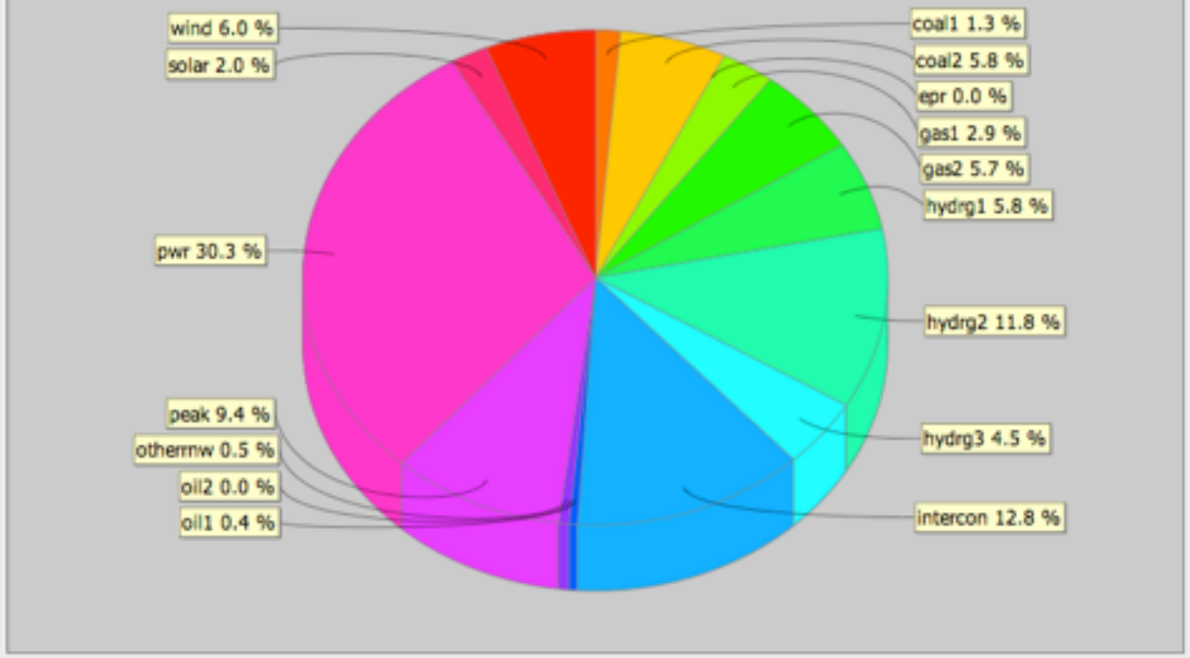
French electricity mix and - 30 GW PWR without replacement (undersized park)

MIXOPTIM - IHM 7.4

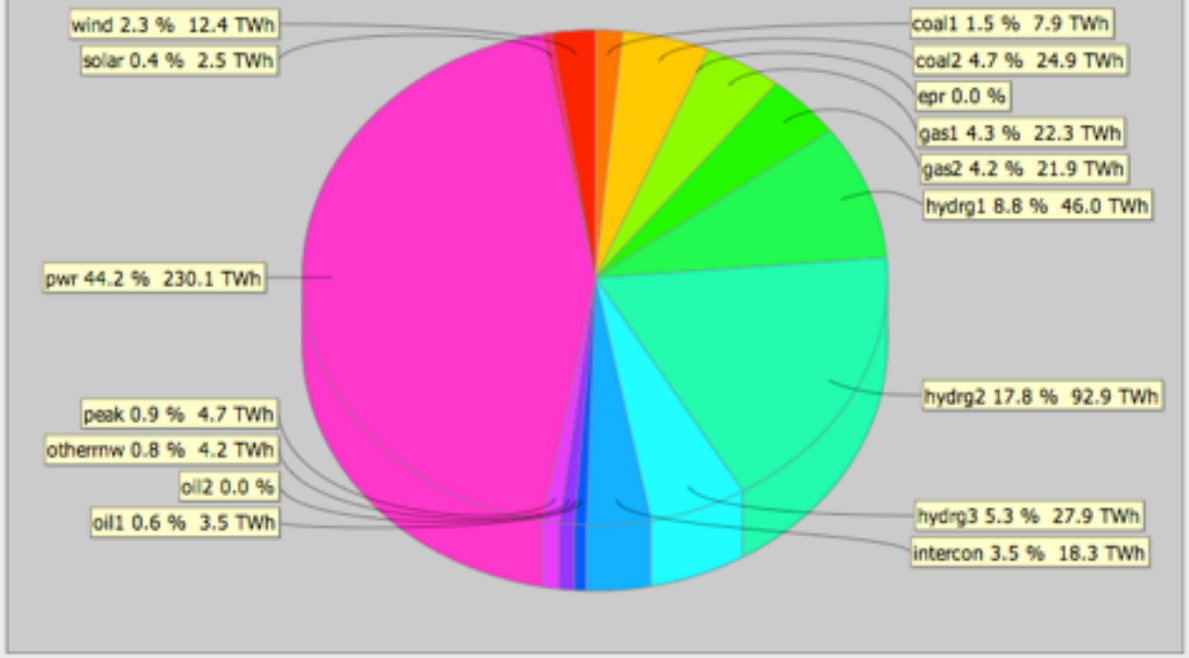
new calculation...

Introduction | manual | calculation | calculation | calculation | calculation

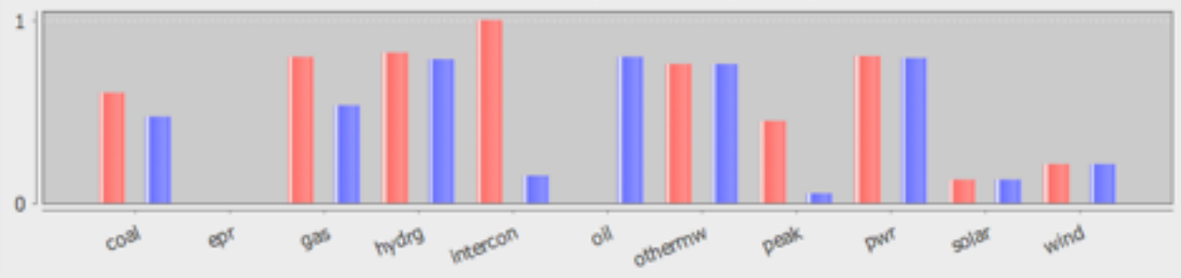
Installed capacity



Actual production



Condensed availability and capacity factors



modify the mix | register the mix | close tab

+12%

```
10 millions of samples
average production cost   47.118 euros/MWh    sigma = 0.00519 %
average demand cost       51.128 euros/MWh    sigma = 0.0033 %
export (gross)            4.327 euros/MWh     sigma = 0.0461 %
average CO2               0.1262 ton/MWh      sigma = 0.00827 %
average produced power    59381 MW            sigma = 0.00441 %
average demanded power    54724 MW            sigma = 0.00698 %
load shedding             1.321 %             sigma = 0.194 %
export                    8.595 %             sigma = 0.0388 %
import                    3.843 %             sigma = 0.0611 %
```

+100%

116 vs 0.02 h/year

MIXOPTIM - MIX STUDY

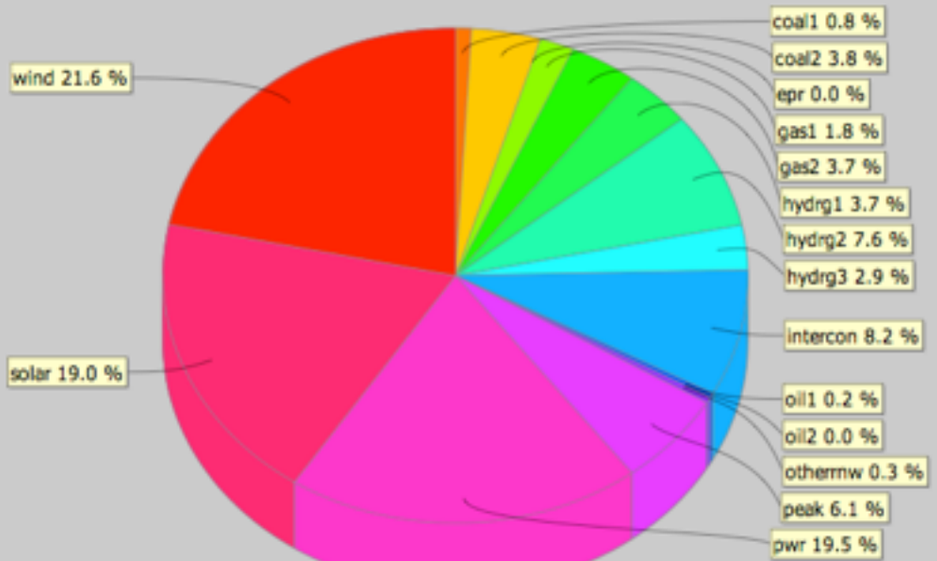
French electricity mix and - 30 GW PWR + 30 GW wind + 30 GW solar

MIXOPTIM - IHM 7.4

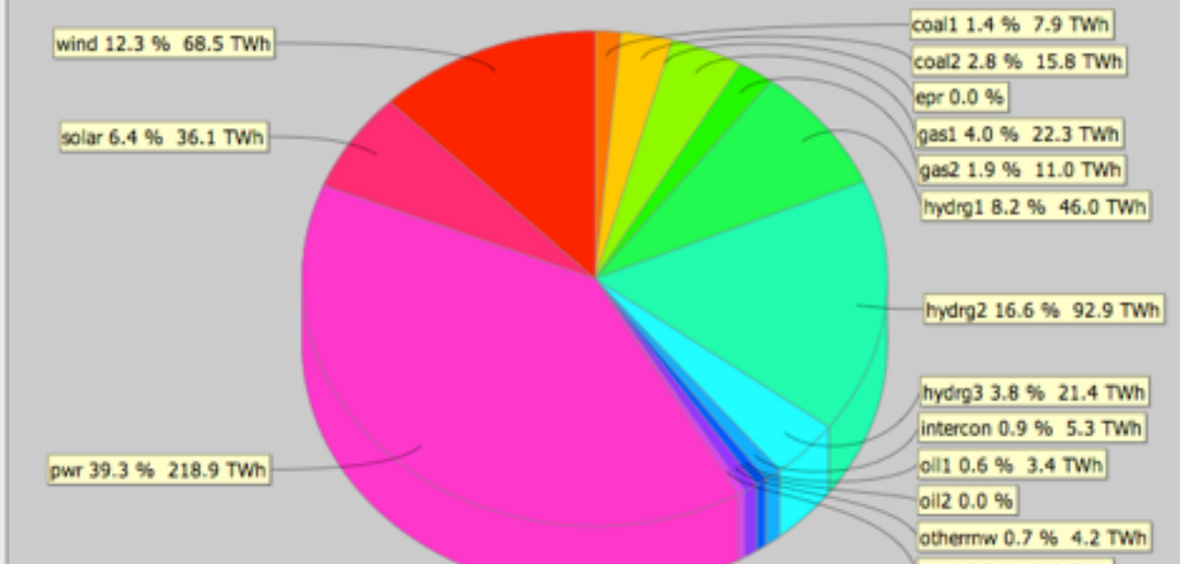
new calculation...

Introduction | manual | calculation | calculation | calculation | calculation

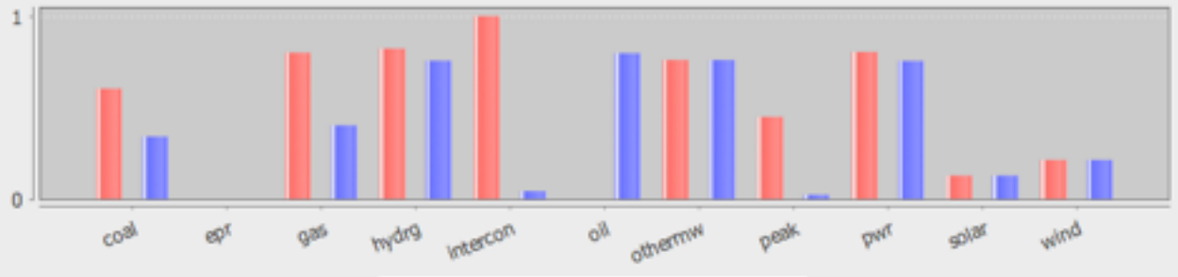
Installed capacity

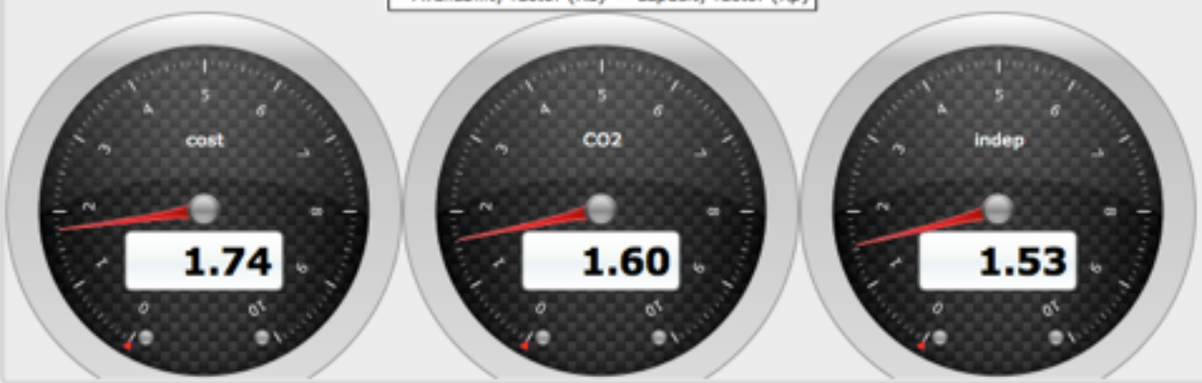


Actual production



Condensed availability and capacity factors





modify the mix | register the mix | close tab

+75% (+12%)

```
10 millions of samples
average production cost   68.756 euros/MWh     sigma = 0.00415 %
average demand cost       79.793 euros/MWh     sigma = 0.0038 %
export (gross)            7.843 euros/MWh      sigma = 0.0286 %
average CO2               0.101 ton/MWh        sigma = 0.012 %
average produced power    63505 MW             sigma = 0.00358 %
average demanded power    54721 MW             sigma = 0.00579 %
load shedding             0.2389 %             sigma = 0.623 %
export                    16.06 %              sigma = 0.0243 %
import                    1.099 %              sigma = 0.101 %
```

+60% (+100%)

21 vs 0.02 h/year

(116 vs 0.02 h/year)

Preliminary results

MIXOPTIM - SCENARIOS

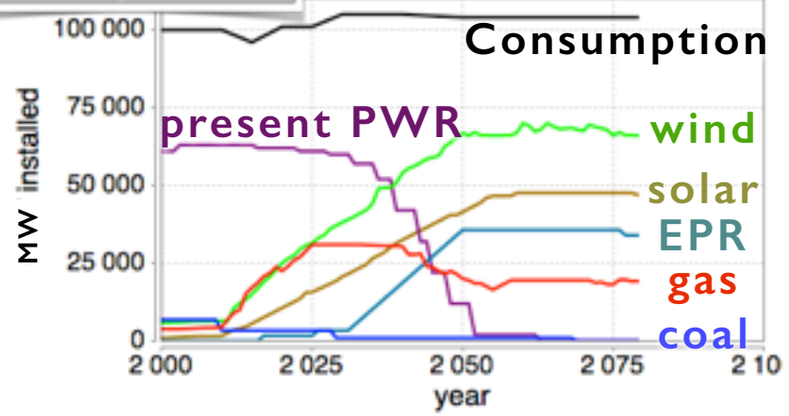
scenario ANCRE DIV - diversification of the power sources + consumption reduction

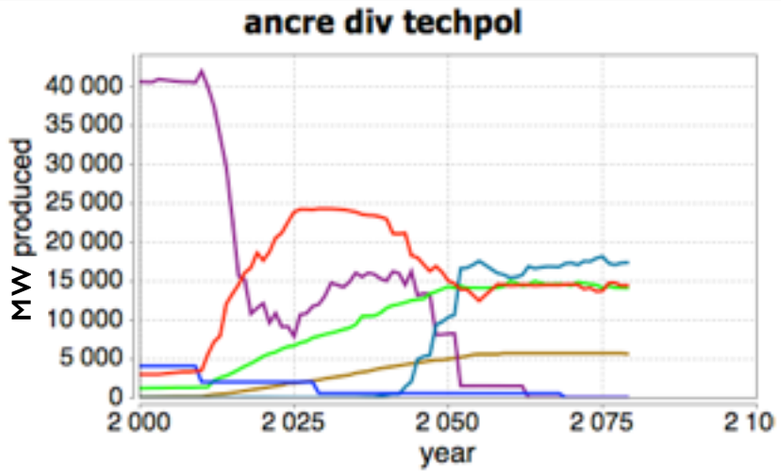
MIXOPTIM - IHM 7.4

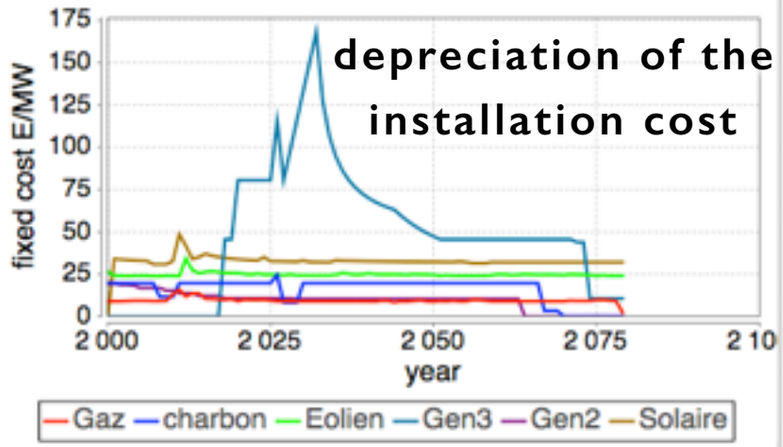
new calculation...

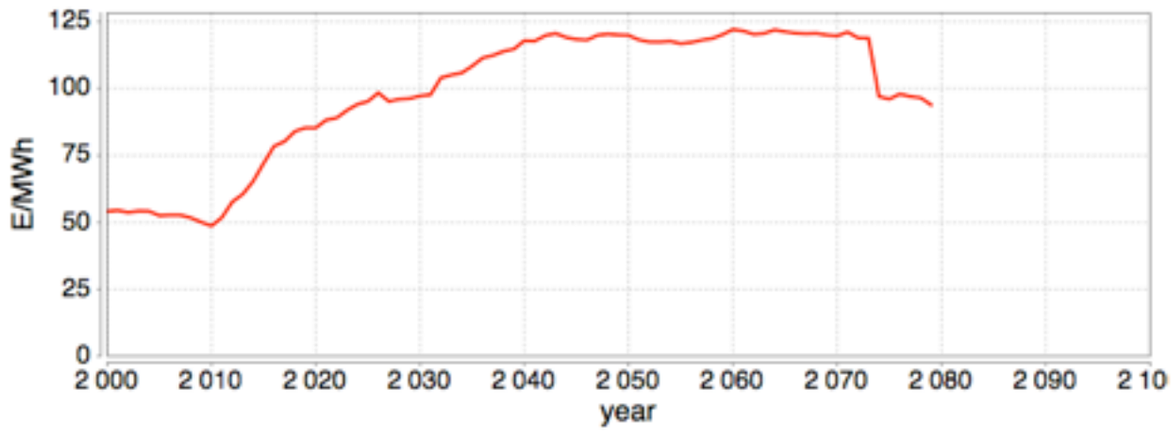
Introduction | manual | scenario | scenario | scenario | scenario

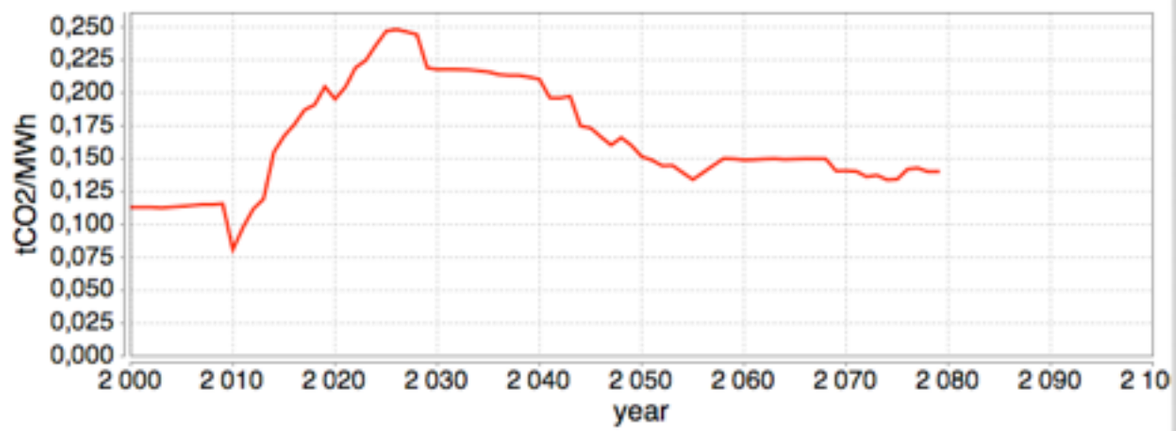
input

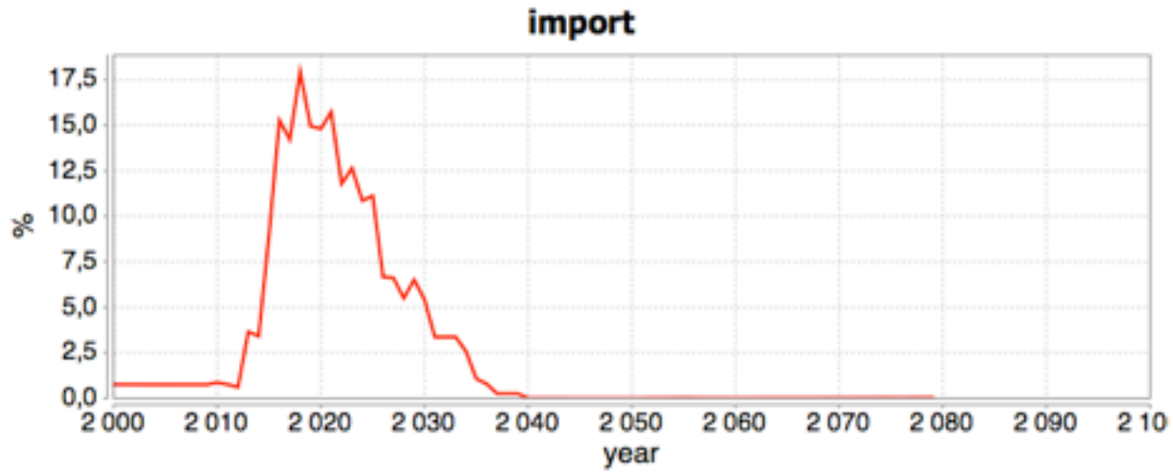


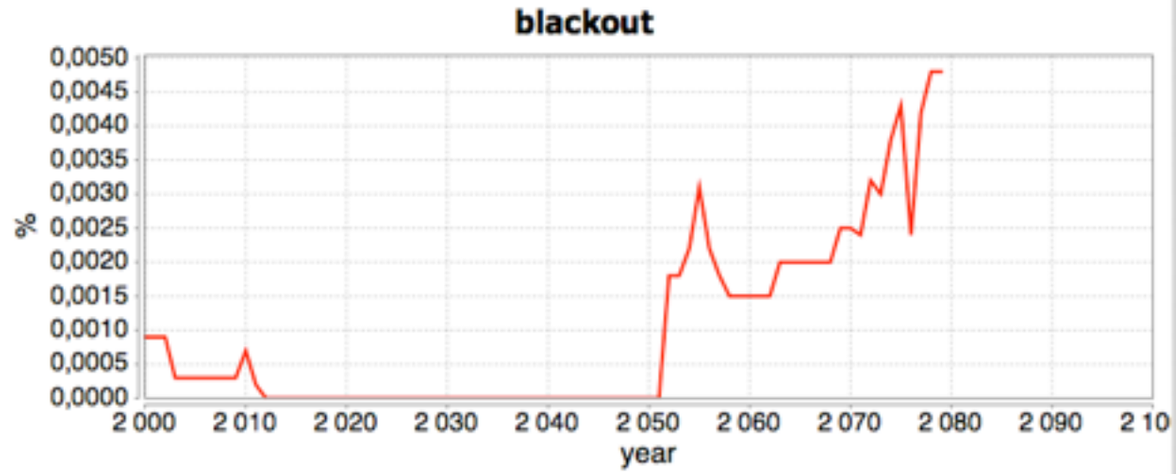












Preliminary results

MIXOPTIM - SCENARIOS

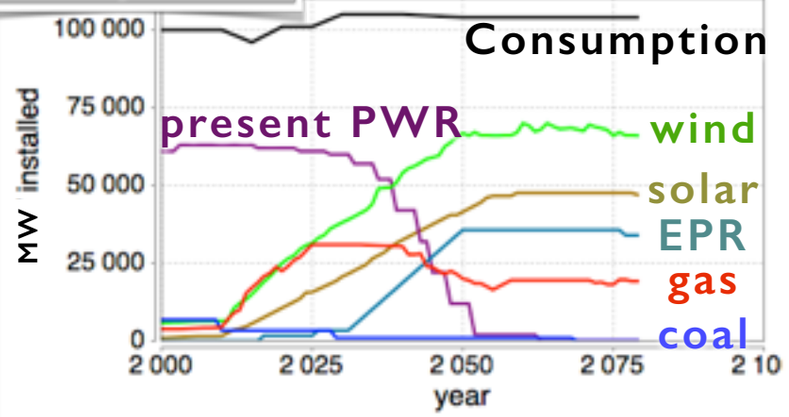
scenario ANCRE DIV - diversification of the power sources + consumption reduction

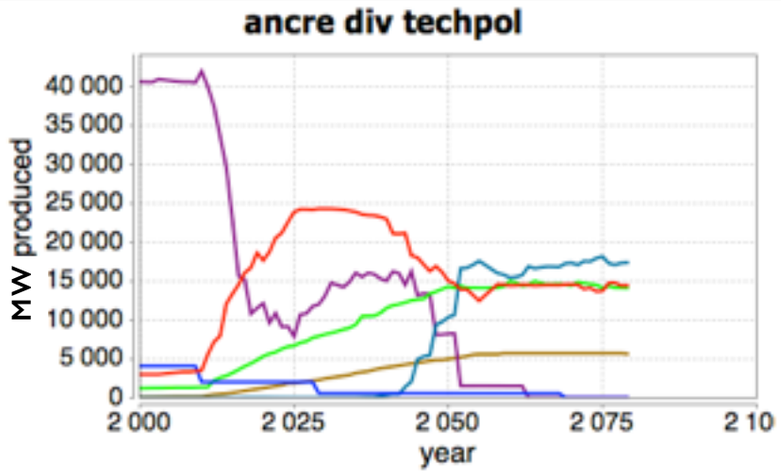
MIXOPTIM - IHM 7.4

new calculation...

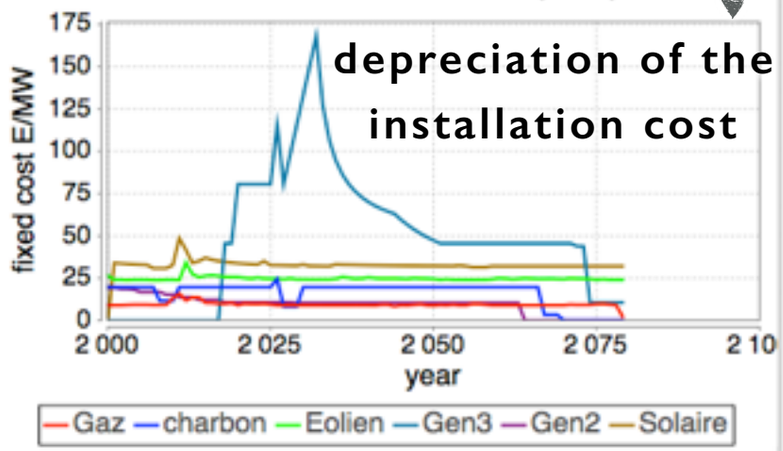
Introduction | manual | scenario | scenario | scenario | scenario

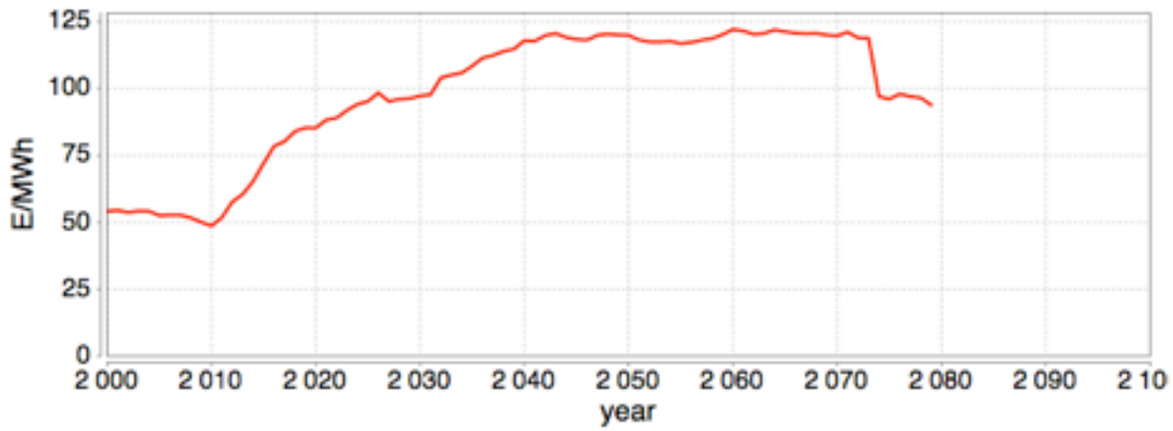
input

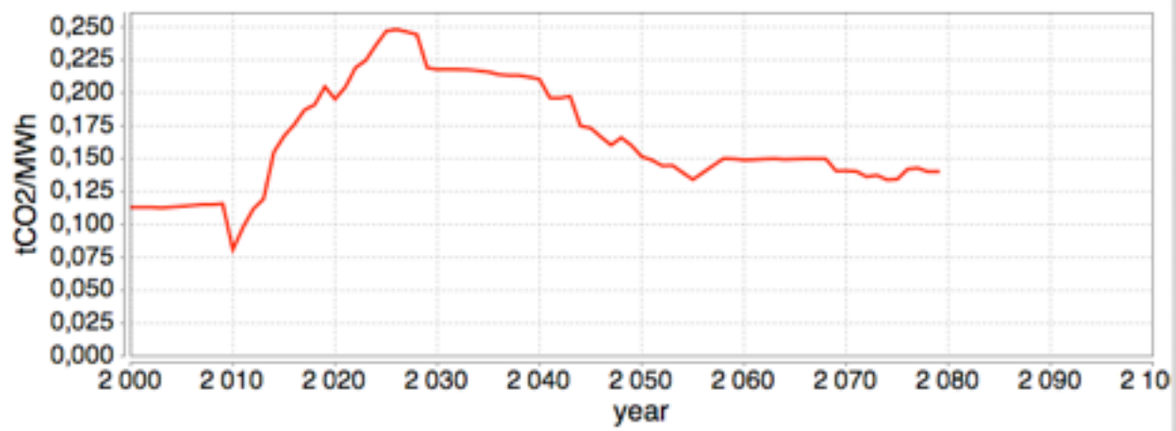


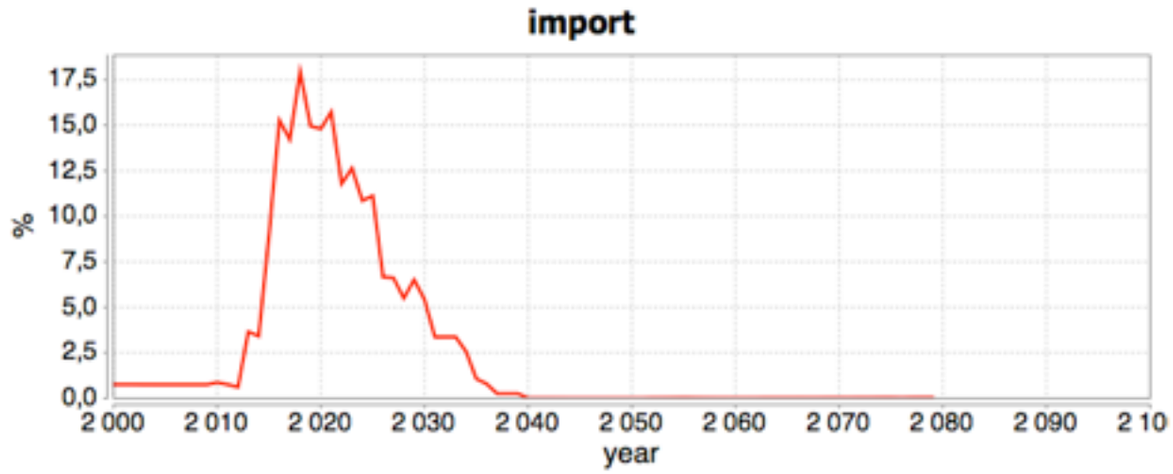


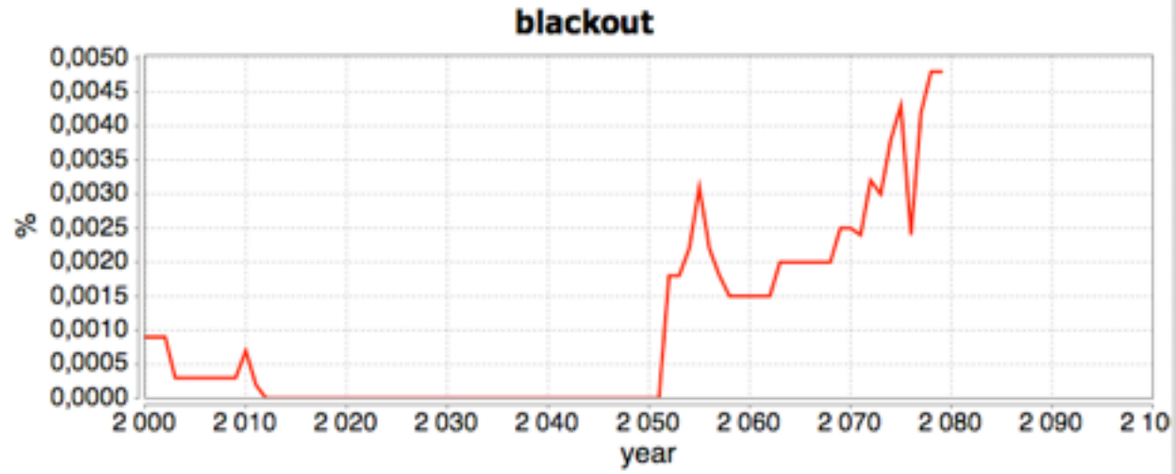
$$F_i(t) = \frac{1}{\alpha_i} \cdot \int_{t-\alpha_i}^{t} \beta_i(t'+\tau_c).\xi_i(t').\frac{x}{1+\frac{1}{(1+x)^{\alpha_i}}}dt'$$







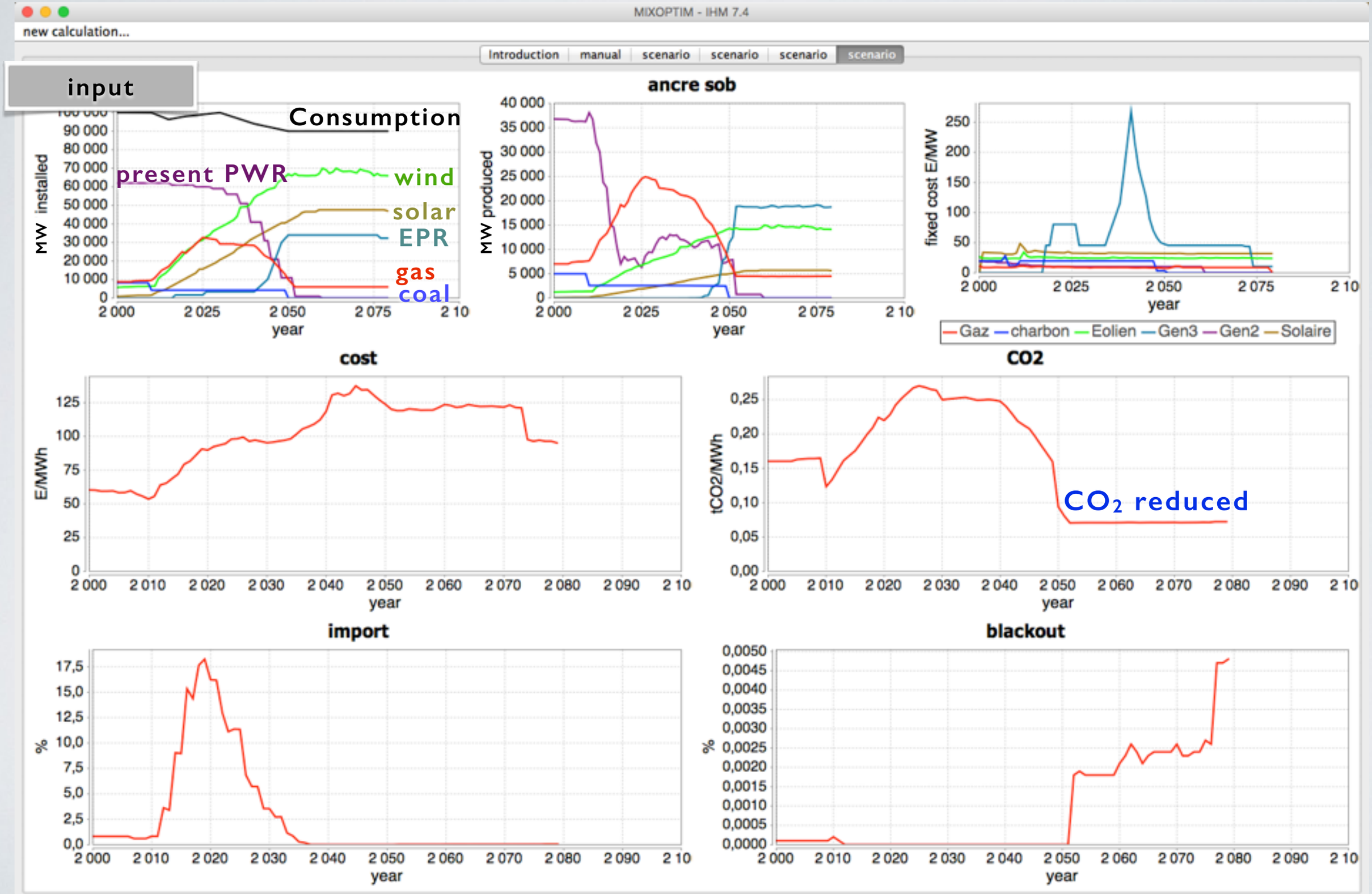




Preliminary results

MIXOPTIM - SCENARIOS

scenario SOB - renewable priority + consumption reduction



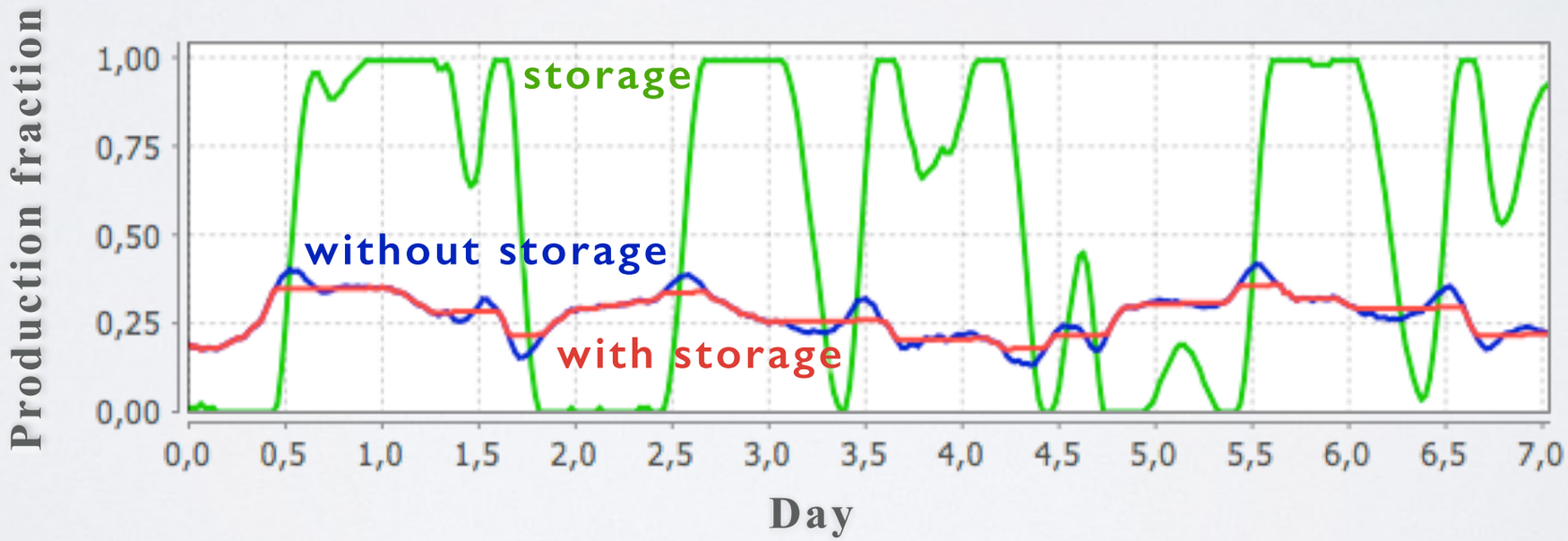
ONGOING DEVELOPMENTS - ENERGY STORAGE

DEPENDING OF SCENARIOS, MASSIVE ENERGY STORAGE WILL BE REQUIRED

Generate chronicles for the storage:
The fatal sources can be mixed in a macro source

- assumption: perfect prediction of the future production
- assumption (so far): no storage yield & no storage limit power ramp

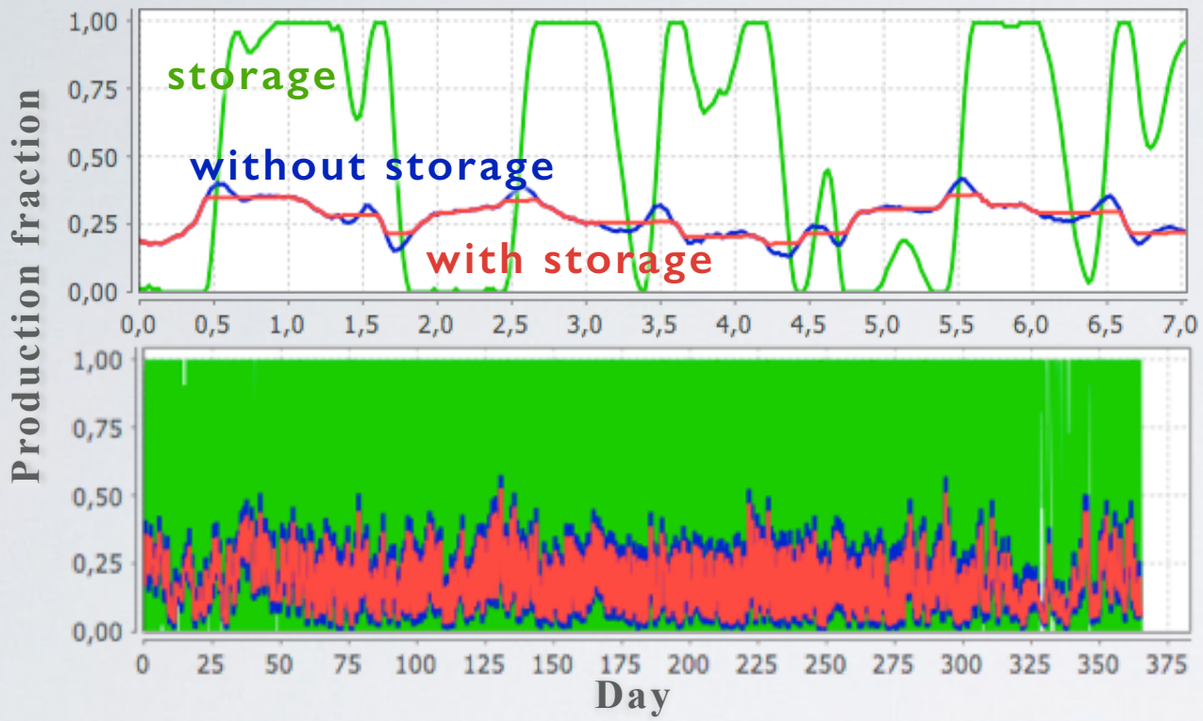
0.5GW solar + 0.5GW wind + storage 0.17GWh (1h at average power)



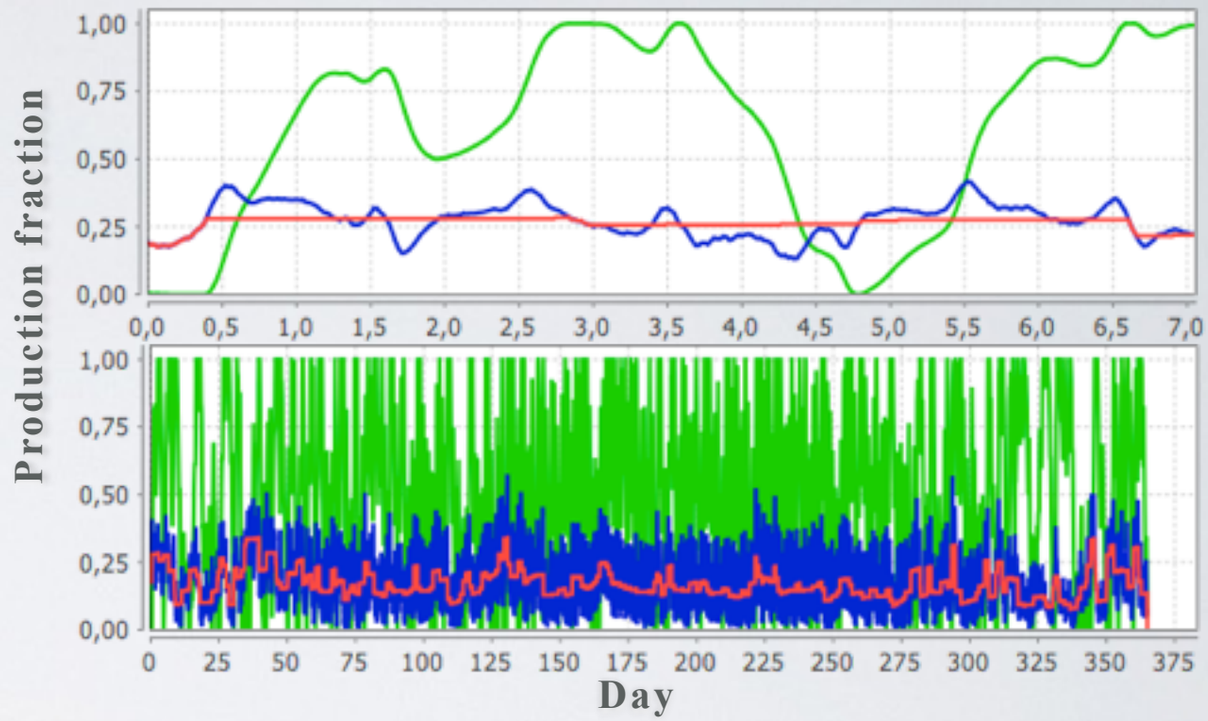
normalized chronicle only depends on the solar/wind and storage/power ratios

ONGOING DEVELOPMENTS - ENERGY STORAGE

0.5GW solar + 0.5GW wind + storage 0.17GWh (1h at average power)



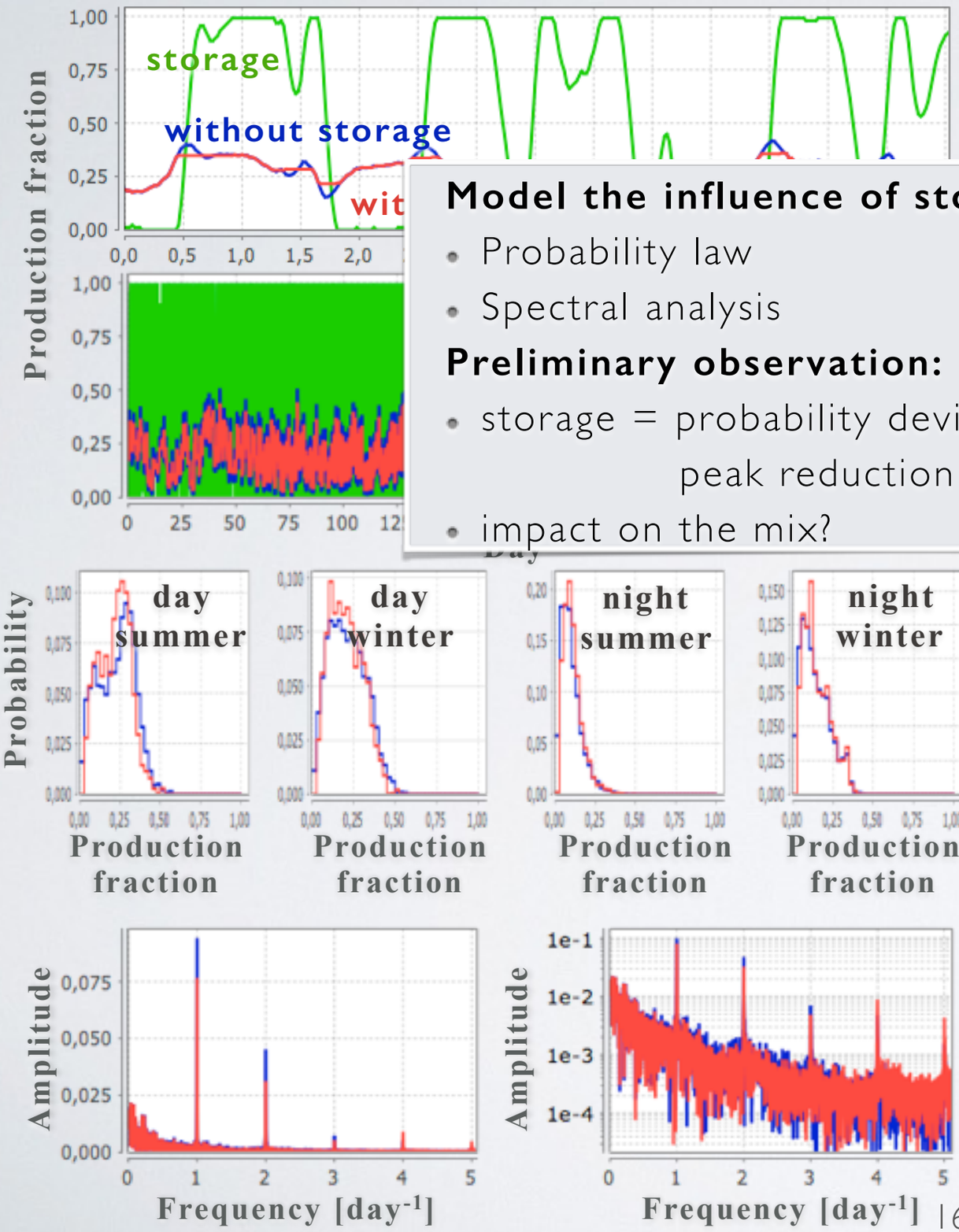
storage 1.7GWh (10h at average power)



ONGOING DEVELOPMENTS - ENERGY STORAGE

0.5GW solar + 0.5GW wind + storage 0.17GWh (1h at average power)

storage 1.7GWh (10h at average power)

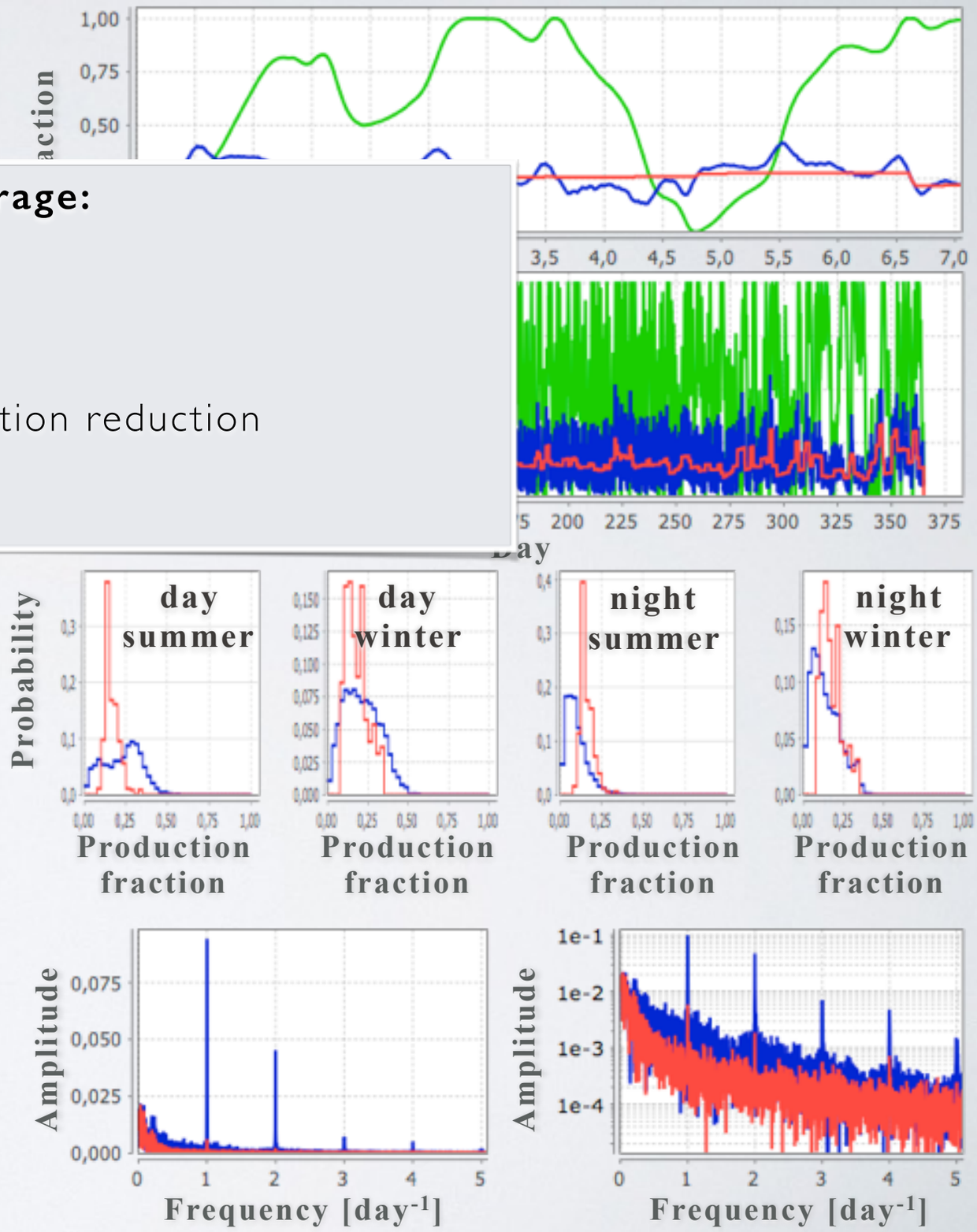


Model the influence of storage:

- Probability law
- Spectral analysis

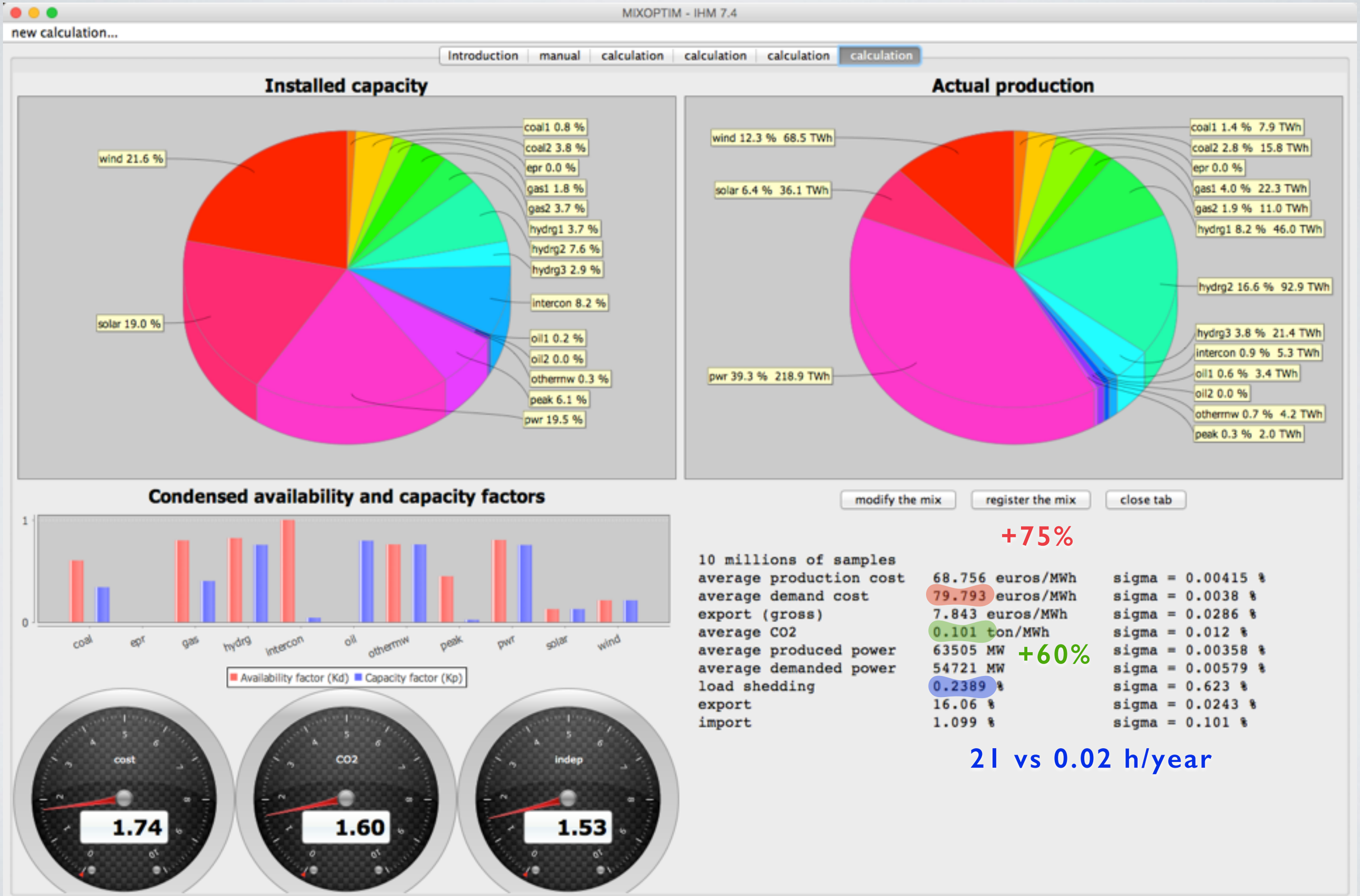
Preliminary observation:

- storage = probability deviation reduction
  peak reduction
- impact on the mix?



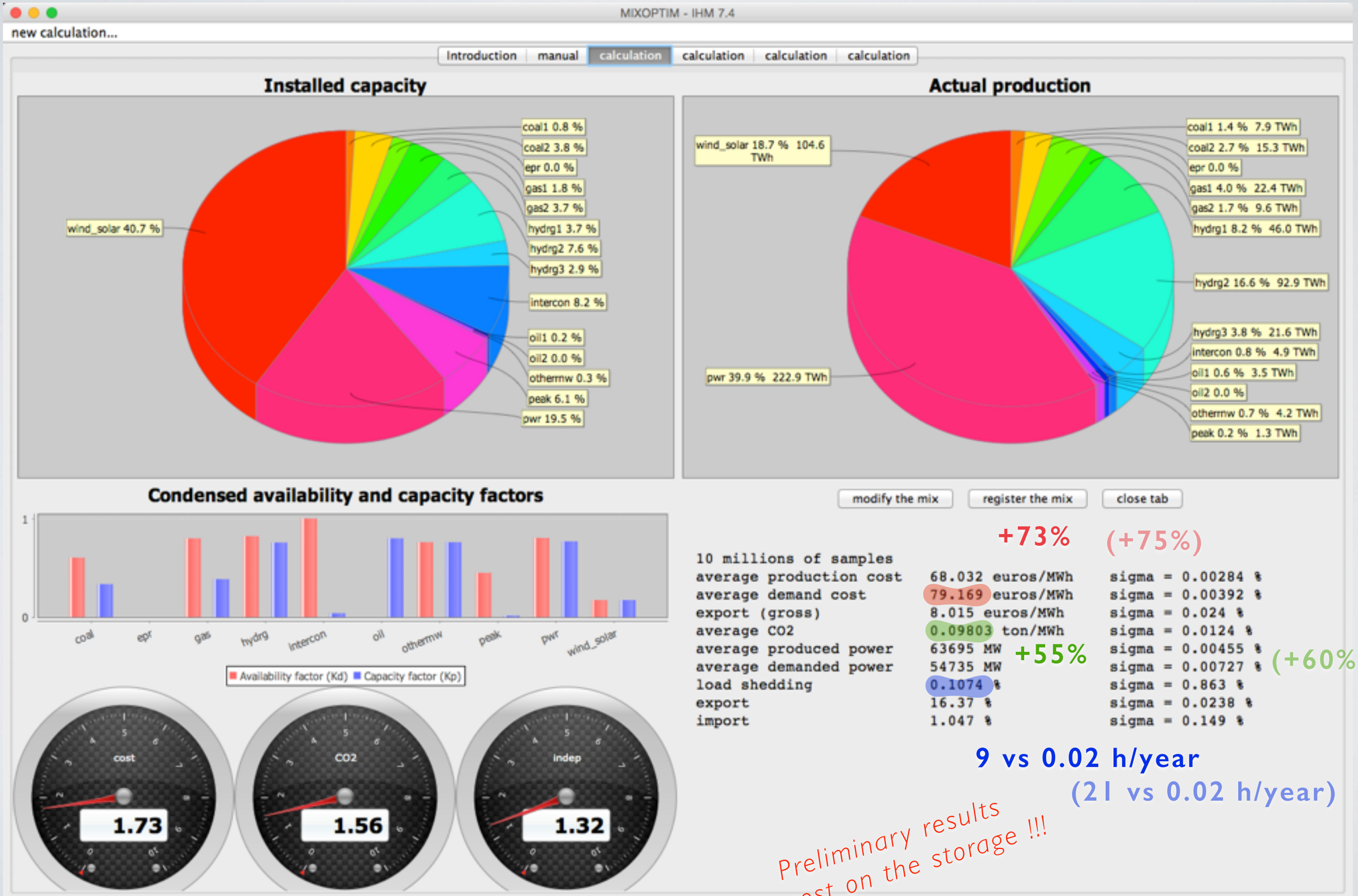
MIXOPTIM - MIX STUDY WITH ENERGY STORAGE

French electricity mix and - 30 GW PWR + 30 GW wind + 30 GW solar + no storage



MIXOPTIM - MIX STUDY WITH ENERGY STORAGE

French electricity mix and - 30 GW PWR + 30 GW wind + 30 GW solar + storage: 10h rnw average power



9 vs 0.02 h/year

(21 vs 0.02 h/year)

Preliminary results
no cost on the storage !!!

ONGOING DEVELOPMENTS - OPTIMIX PROJECT - NEEDS PROGRAM

Le projet consiste à simuler le fonctionnement d'un mix électrique sur un territoire pour explorer les **limites physiques d'introduction des renouvelables dans le mix**, du point de vue de sa capacité de suivi de charge. On se propose d'utiliser pour cela le logiciel de simulation MIXOPTIM, qui fait l'**analyse spectrale** des fluctuations de la charge, pour en déduire la capacité maximale acceptable en éolien et en solaire dans un mix, en fonction des hypothèses retenues sur les fluctuations de la demande et sur l'agilité des sources pilotables présentes dans le mix.

Dans un deuxième temps, on se propose de regarder comment les limites d'introduction des sources renouvelables fatales déterminées dans la phase I sont déplacées par le **stockage et l'interconnexion**. Il est également envisagé d'étudier ce que deviennent les limites si on cesse de **considérer l'éolien et le solaire** comme des sources fatales, et si on en fait des **sources pilotables à la baisse**.

physical limit of renewables in the mix

spectral analysis

storage
interconnection

renewable = downwards controllable source

	CEA	CNRS	IRSN
partners:	Bernard Bonin Axel Laureau Henri Safa	Elsa Merle Nicolas Thiollière	Erci Dumonteil Joachim Miss Yann Richet