Le réseau de l'intelligence électrique

Antares

Probabilistic tool for Electric Systems

***A N**ew **T**ool for **A**dequacy **R**eports and **E**conomic **S**imulations*

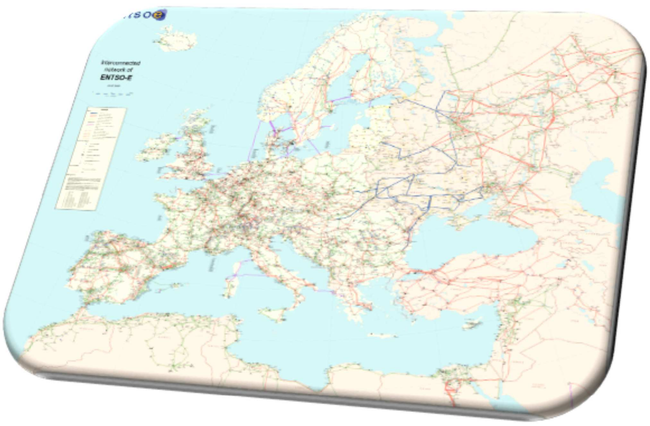
Context

Growing interconnection level

Enlarge geographic perimeter of the analysis

A less deterministic system (renewables, time dynamic, combination of events)

Sequential and probabilistic approaches required



Le réseau de l'intelligence électrique

Introduction

ANTARES is a Monte-Carlo software for power systems analysis…

- Sequential
- Multi-areas
- With a time span of one year
- With a time resolution of one hour

Designed for

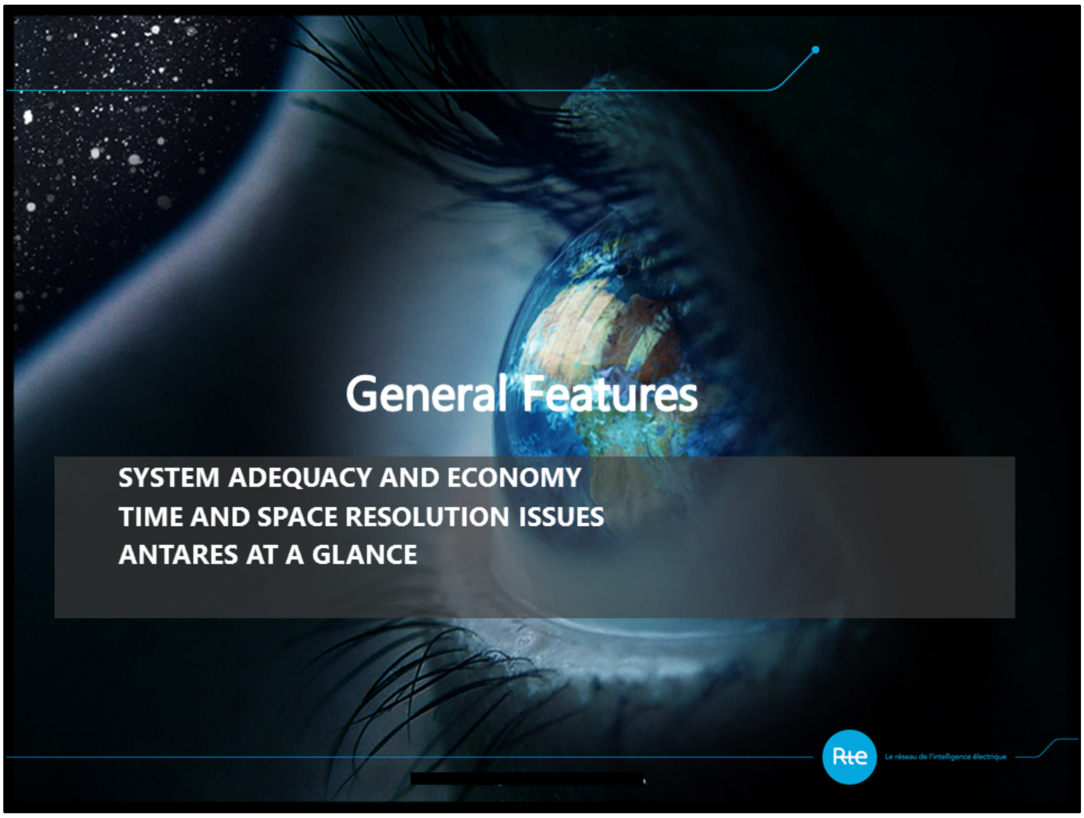
- Generation / Load balance studies (Adequacy)
- Economic assessment of Generation projects
- Economic assessment of Transmission projects

Not designed for

- Studies of large systems without simplification
- All technical studies

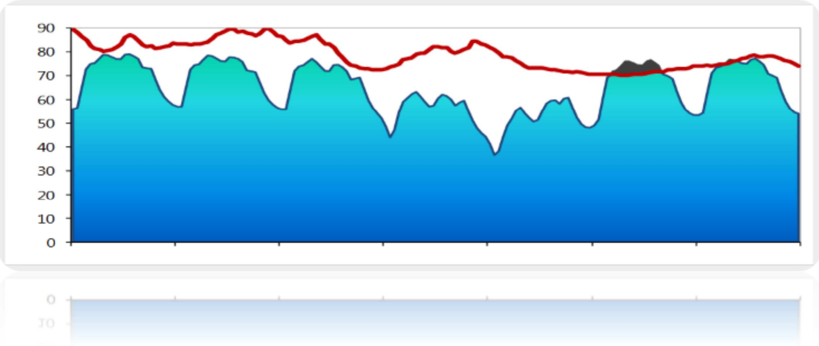
Contents

CONTENTS :


General Features
SYSTEM ADEQUACY AND ECONOMY
TIME AND SPACE RESOLUTION ISSUES
ANTARES AT A GLANCE

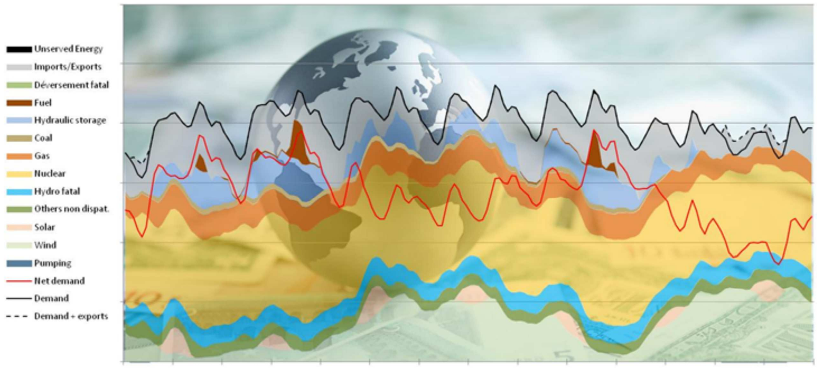
Designed to respond to adequacy questions

For each area: How often / How long / How much unserved energy ?



And to economy questions

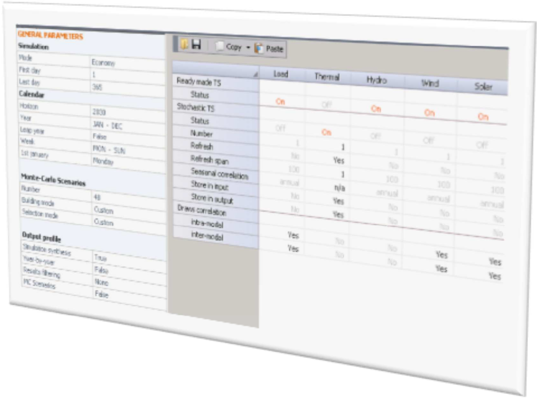
For each node, each energy: | How many (TWh)
How many (M€)
How many (CO2 tons)



Adequacy and Economy

Different modes of simulations

- Economy, Adequacy
- Selection of MC years within a set
- «What If » step-by-step scenario building



Le réseau de l'intelligence électrique

Antares offers different modes of simulation:

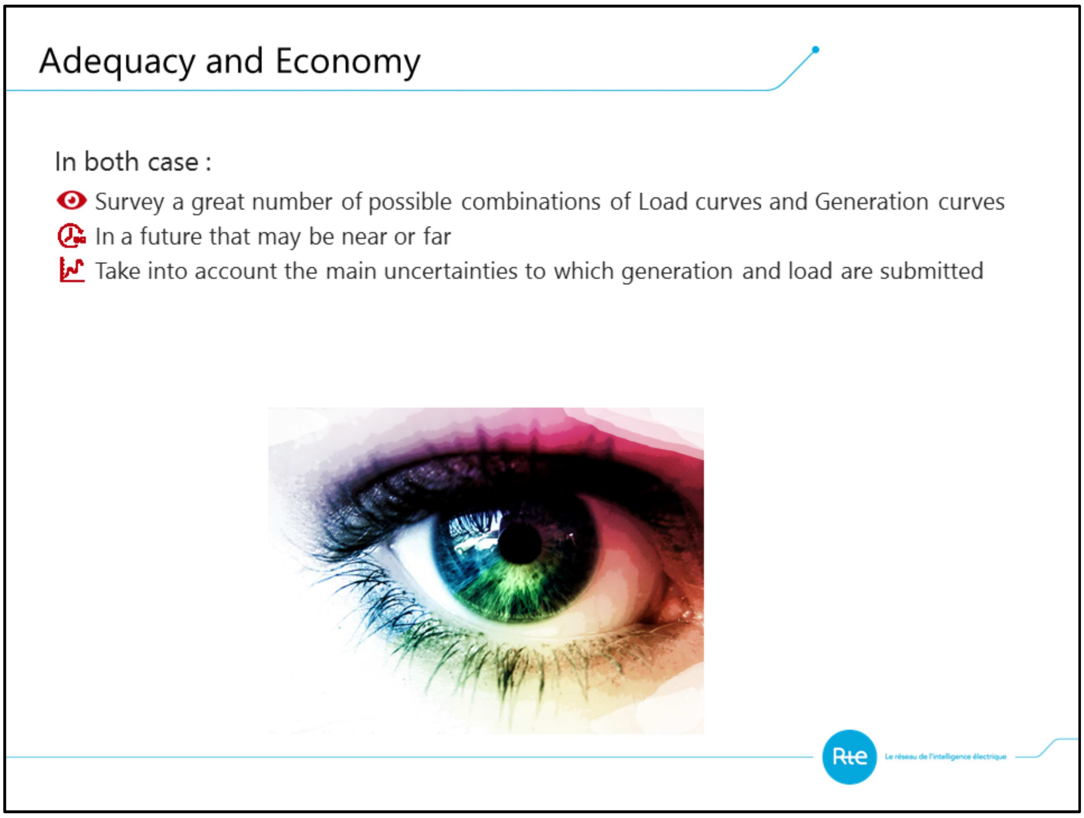
1 The “Adequacy” mode is dedicated to loss of load assessment:

Loss Of Load Probability, Loss of Load Expectation , Cost of Unsupplied Energy (i.e. Unsupplied Energy * Value of Lost Load - VOLL)

2 The “Economy mode” gives access to a detailed description of both optimal unit commitment and schedule.
Various representations of constraints on thermal units make it possible to adjust the trade-off between accuracy and runtime

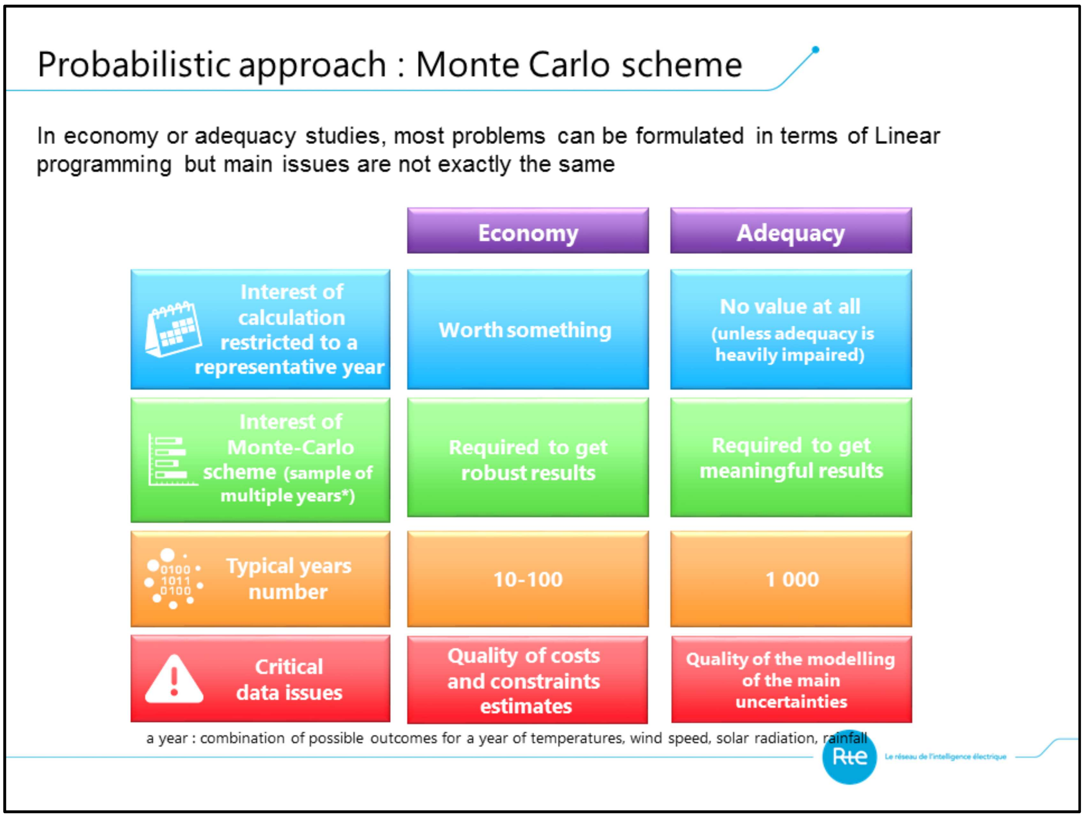
In both modes, Antares offers several ways for choosing the set of time-series to use in the course of simulations:

- Explicit selection of the time-series to use (“what if” scenarios) or choice by pure random draws (genuine Monte-Carlo)
- Time-series selection or draws maybe be committed to fit consistency rules from a meteorological standpoint
- Simulations may include or not all of the previously defined scenarios (so-called “Monte-Carlo years”), according to the content of a “playlist”



Antares has been designed to simulate efficiently a great number of possible combinations of Load curves and Generation curves:

Uncertainties taken into account are hydraulic inflows, thermal availabilities, wind and solar power intermittency, load sensitivity to climatic conditions.
Antares is today used for studies ranging from operation planning (a few months) to long term expansion issues (2050).



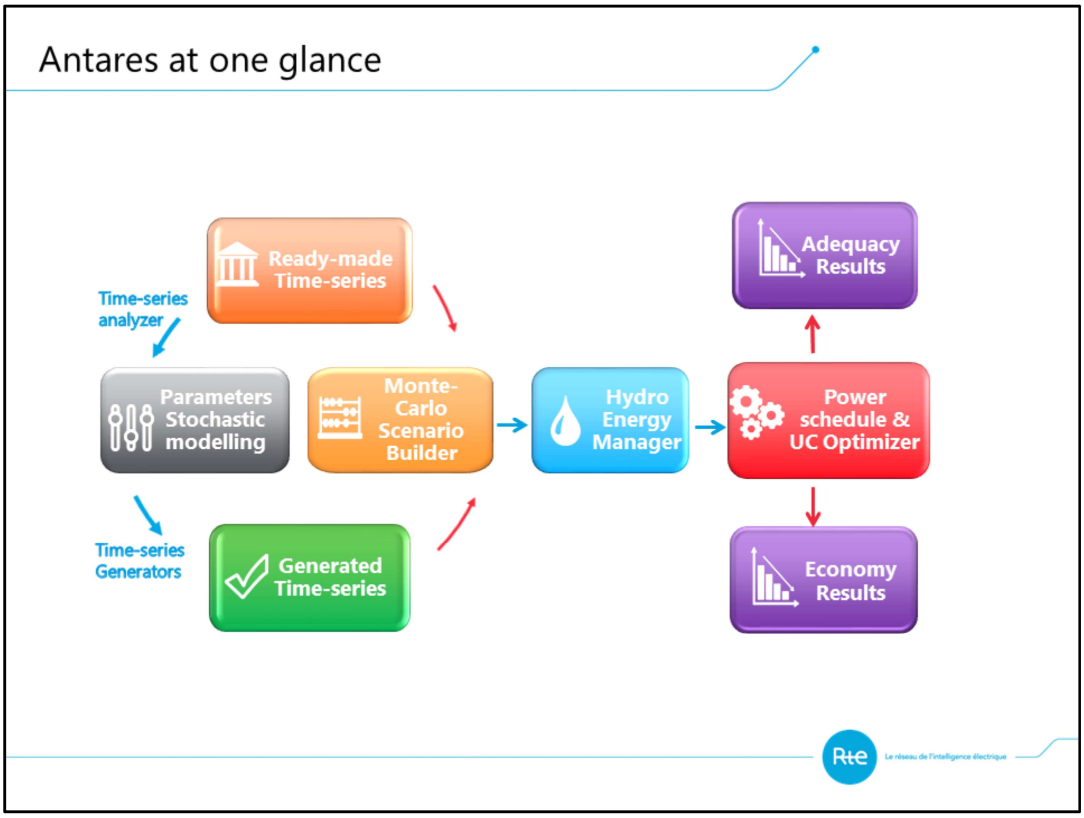
The influence of climatic conditions on adequacy makes it mandatory to run many scenarios to gather meaningful results from a statistical point of view. In RTE's experience, 1000 simulations are usually required for convergence of indices such as loss of load duration and unsupplied energy expectation. Even more simulations may be required for risk indicators based on low statistical thresholds.

For economic studies, fewer "years" are required. The tool makes it possible to go as far as simulating only one year, which may be defined by "derated" conditions. However, this option has to be used with great care because in most cases the specific effects of many random phenomena are damped by the averaging out pre-processing. Likewise, simulating only one deterministic year (chosen to fit a particular set of realistic, but limited, conditions), though possible, gives a poorly informed view of the actual stochastic behaviour of the system.

This is why the practical interest of these two options is mainly to allow easy and quick assessment of particularly well pre-defined "what if" scenarios (which may come to be of interest at some point in the course of almost every kind of studies).

In RTE's experience however, the basis of most economic studies should involve a batch of simulations runs in the range of 100 Monte-Carlo years, so as to achieve a good balance between results accuracy and runtime.


Simulation scheme & Optimization
SIMULATION SCHEME
OPTIMIZATION IN ECONOMY
OPTIMIZATION IN ADEQUACY



Demand levels, wind, solar, hydraulic and available thermal productions are either provided by the user in ready-made time-series or directly generated by ANTARES when it is supplied with stochastic parameters. These parameters may be known from other studies or provided by a built-in time-series analyzer which can work on available ready-made time-series.

For clarity's sake, assume that the number of available ready-made time-series is **n** and the number of time-series required for proper statistical modeling in simulations is **m** :

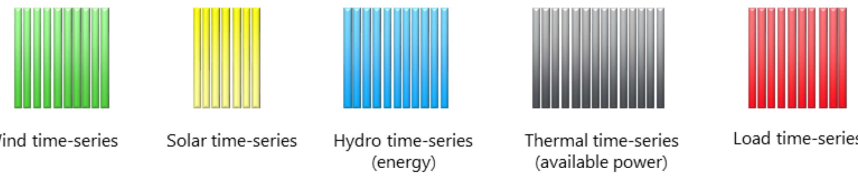
If (**n** >**m**) The available ready-made time-series may be used straight away in simulations
If (**n** <**m**) and robust stochastic parameters are known to start with: generate **m** time-series with these parameters
If (**n** <**m**) and no values are known for stochastic parameters: derive said stochastic parameters through the analysis of the **n** available TS, then generate the required **m** TS

The next step is that of seasonal hydropower volumes pre-allocation (based on the net demand pattern – Load minus RES and must-run generation).

The determination of the optimal hydro-thermal unit-commitment and dispatch throughout the year is then carried out week by week. Problems are formulated in terms of linear programming (sometimes including mixed-integer programming steps)

Simulation scheme

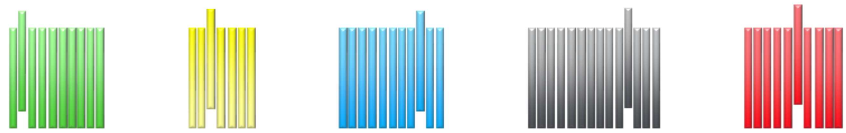
Step 1 : Creation of annual time-series for each parameter



- For each parameter, **generation** or **retrieval** of **year-round time-series** , with an **hourly resolution**.
- Usually, from 10 to 100 time-series for each parameter (many more if required).
- Single time-series for parameters deemed constant from one year to the next (geothermal generation,...)

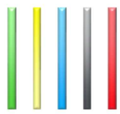
Simulation scheme

Step 2 : Creation of a Monte-carlo scenario (year)



Selection of a time-series for each parameter **at random** or based on **user-defined** rules (**probabilistic/deterministic** mixes)

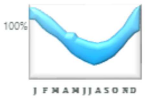
The output of this phase is an annual scenario for demand and generation called a « Monte-Carlo year »



Simulation scheme

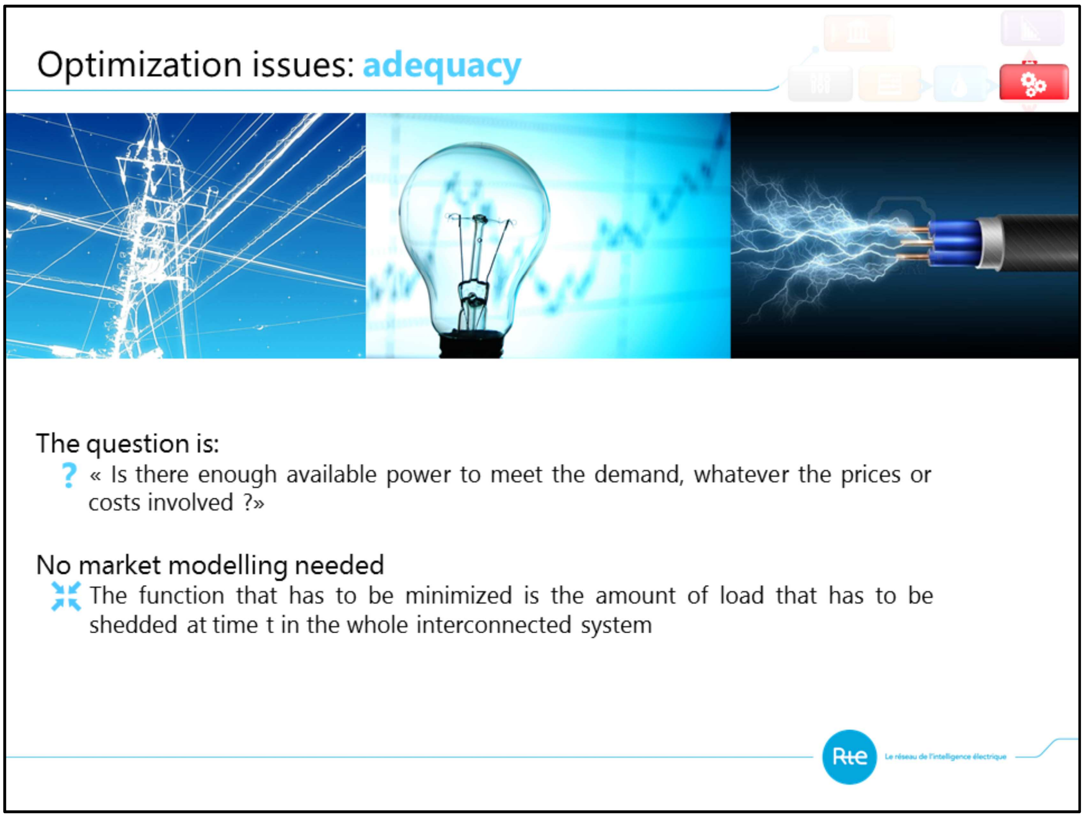
Step 3 : Hydro storage energy management

The annual or monthly hydro storage energy is broken down into weekly amounts through an heuristic based on :

- Scenario data (Load, fatal, Must-run): allows the calculation of net demand
- Hydro management policy parameters: allows to define how net demand is ponderated for the repartition of energy from year to month and from month to week
- 

Reservoir rule curves: allows to define minimal and maximal curves to constrain the repartition of hydro energy and to define variation of Maximal power with variation of level of reservoir

Le réseau de l'intelligence électrique

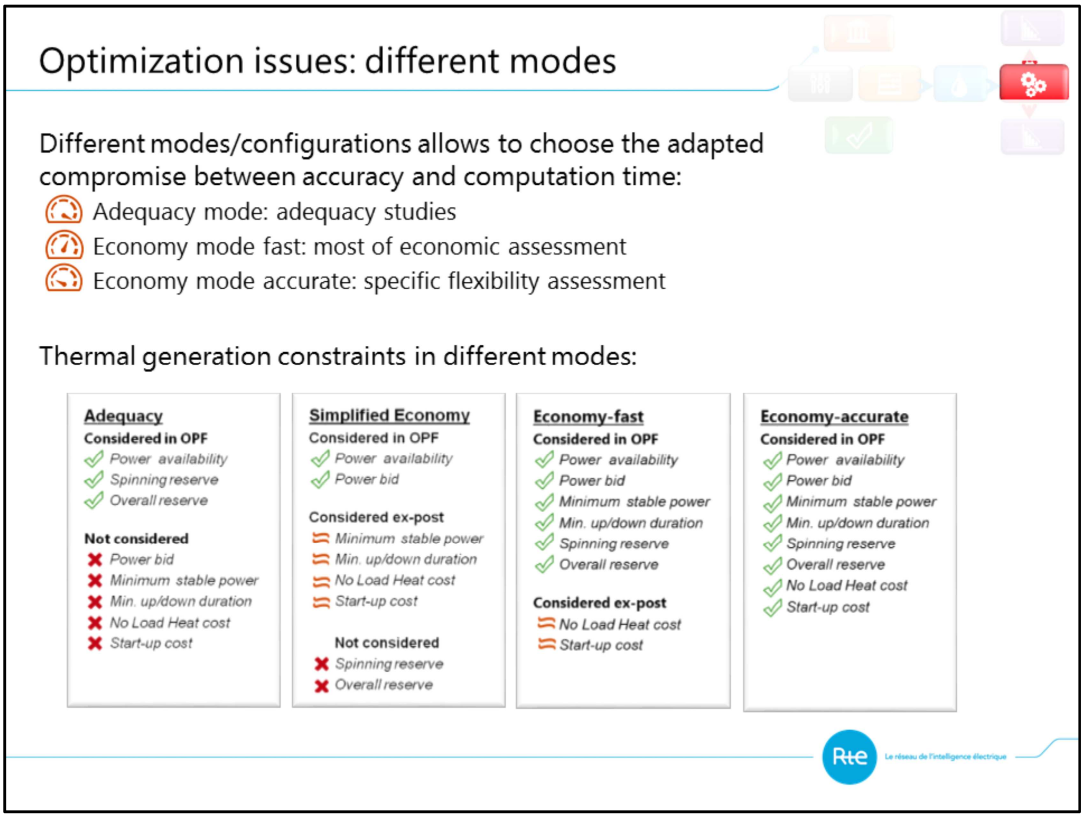


The “Adequacy” mode of ANTARES is dedicated to the analysis of the electric margins of an interconnected system

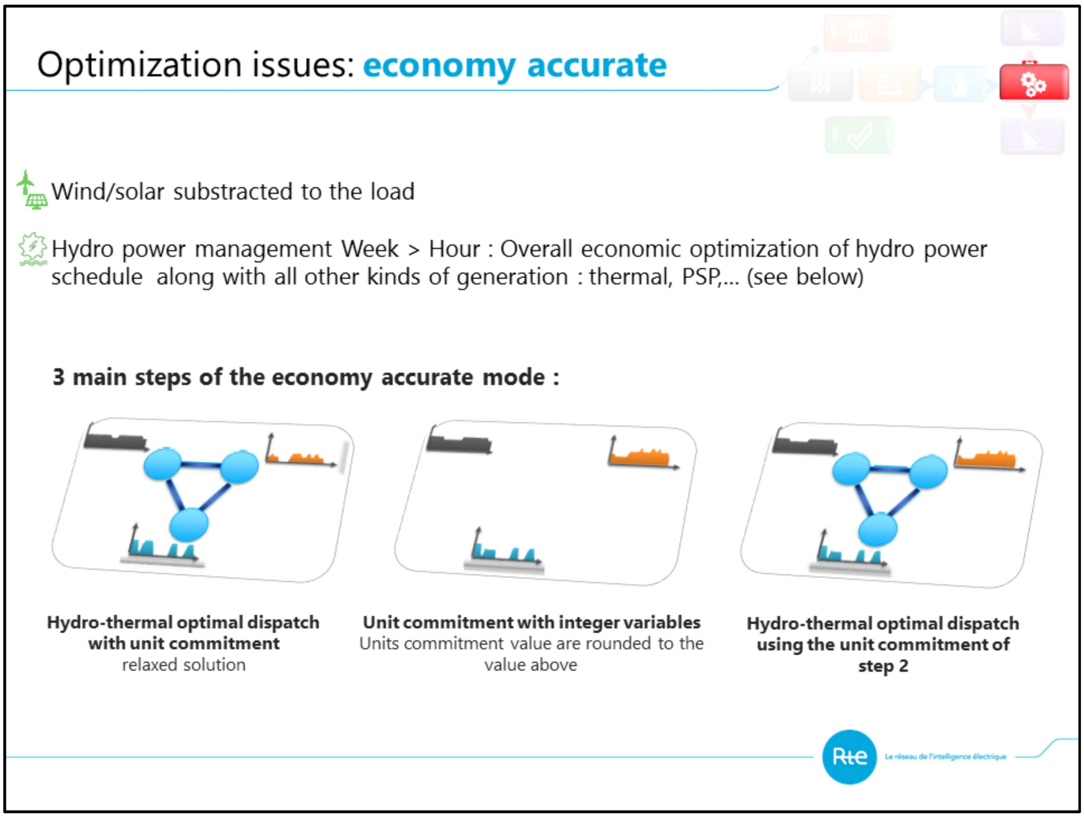
No information on production costs, nor fine dynamic constraints of power plants are taken into account in this mode, resulting in a shorter optimization time.

The “Economy” mode gives access to more complex economic and physical constraints of the production units:

- Market bids,
- Startup costs and No-load heat-cost,
- Minimum up and down times,
- Temporal postponement for energy use (demand-side management, pump storage…).



For advanced users, various options allow to increase or decrease the complexity of the economical and physical modeling of the power system components.



Three main steps of the “accurate” unit-commitment and dispatch mode:

1- Optimal dispatch and unit commitment

- Reserves are included in load
- Minimal power, minimum on- and-off durations and non-proportional costs are considered
- Integer variables are relaxed

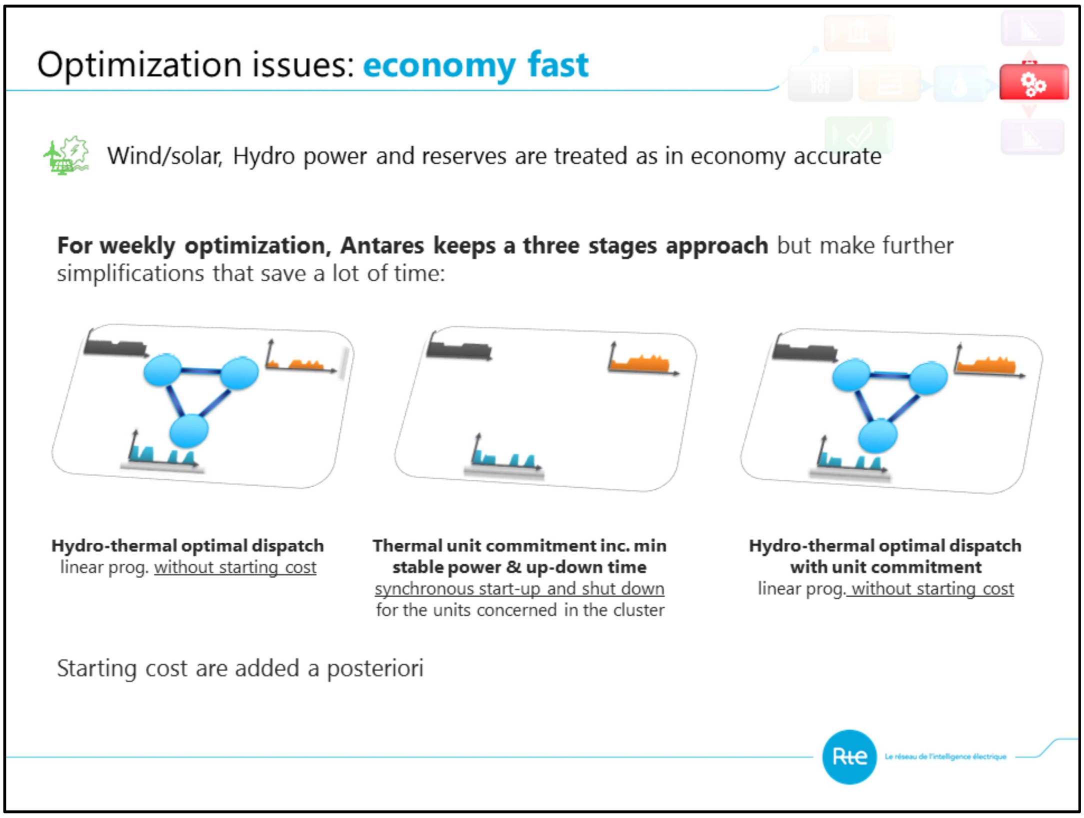
2- Rounding of integer variables through a heuristic yielding a feasible solution close to the relaxed solution calculated in step 1

3- Optimal dispatch constrained by the unit commitment of step 2

– Reserves are no more included into the load

Breaking down the whole MILP in three pieces makes it more tractable while yielding an acceptable accuracy

(in RTE’s experience, results do not stray more than a 10-3 factor from the « perfect » frontal solution)

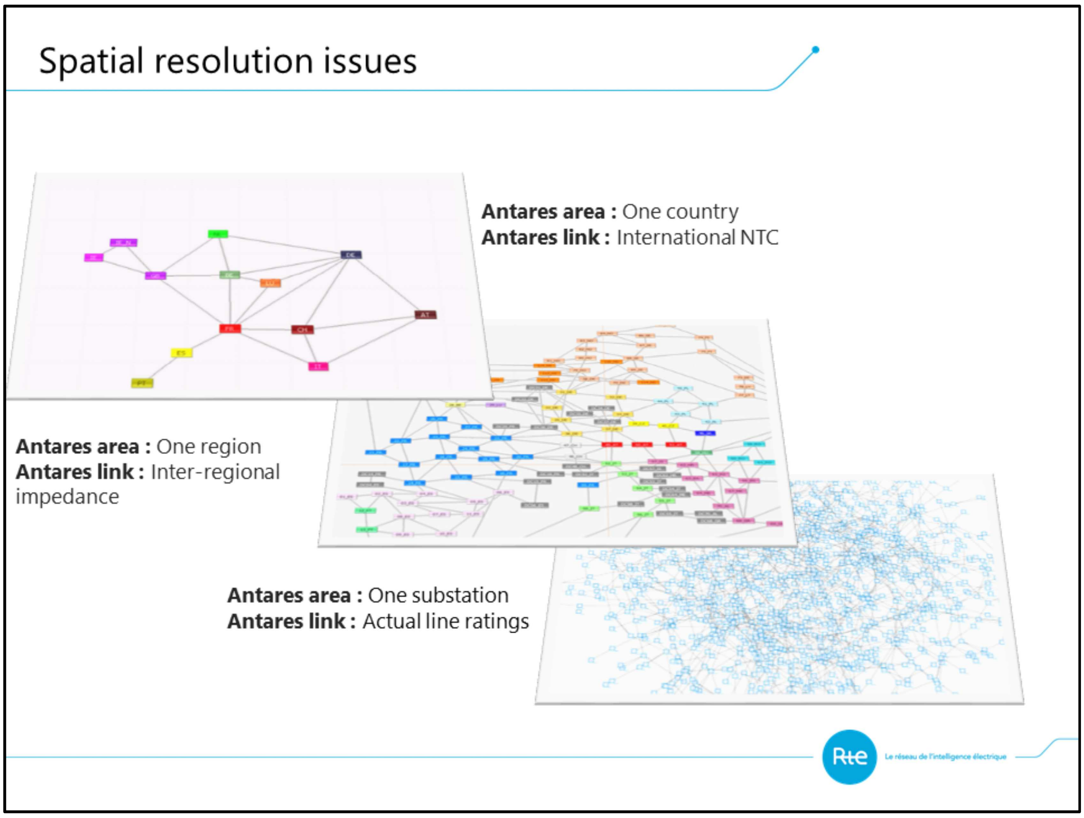


Further simplification in the “fast” unit commitment and dispatch mode:

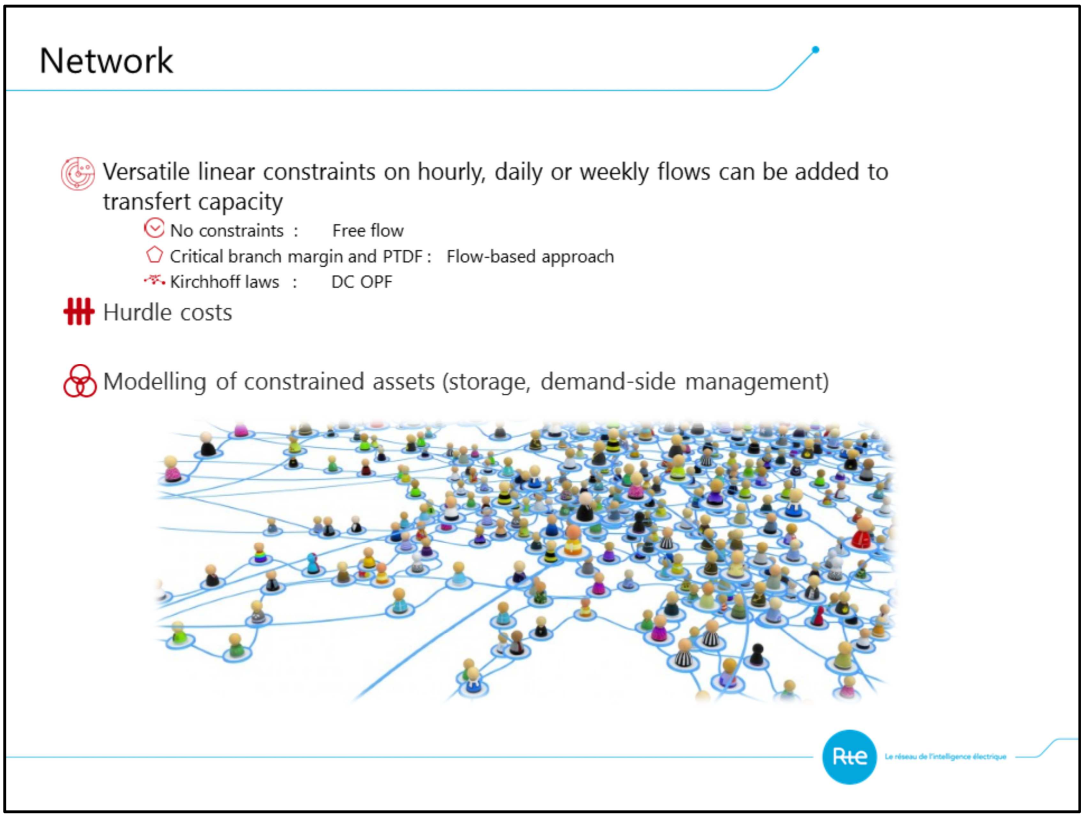
- Start-up costs and no-load heat costs are not taken into account within the optimization step but are minimized afterwards
- Units within a thermal cluster are subject to start-up/shutting down constraints more stringent than the minimum up/down durations

Modeling options

- NETWORK
- LOAD/WIND/SOLAR
- DSM
- HYDRO GENERATION
- THERMAL GENERATION
- RESERVES



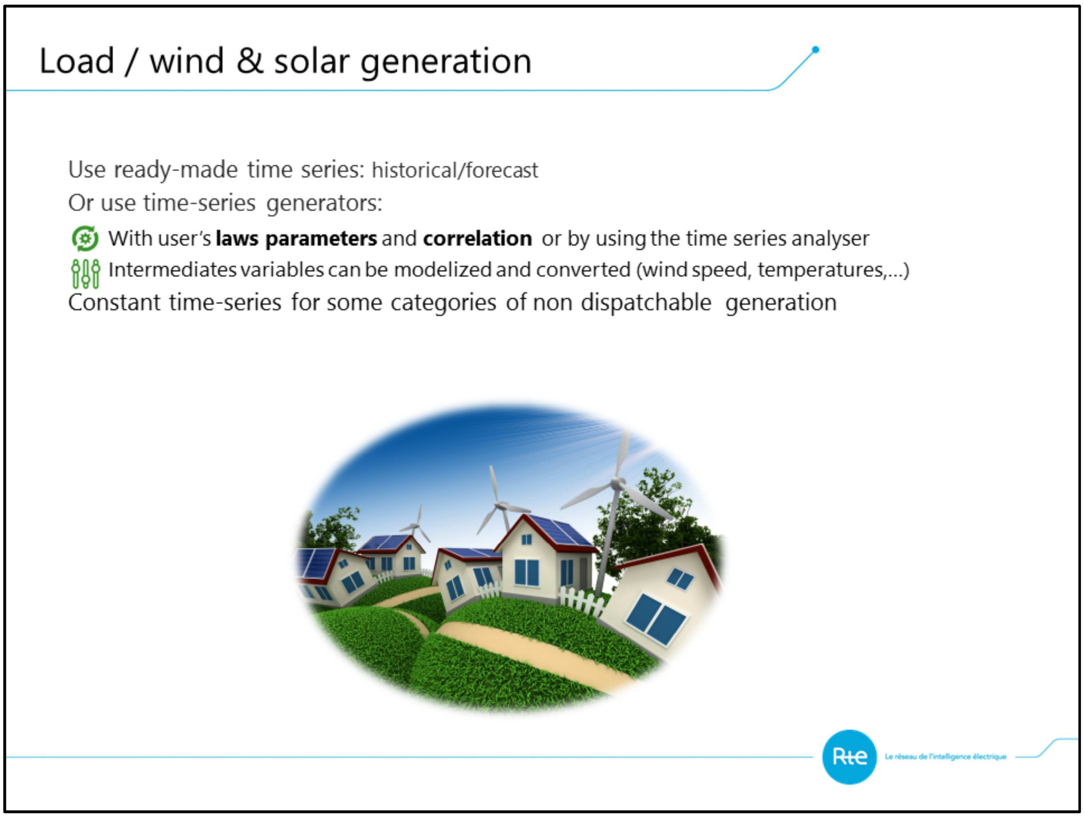
Antares represents interconnected areas. Different spatial resolutions are possible for those areas, from country to substation level



A crude first-order grid model can be set up by using basic transfer capacity time-series (hourly values, either symmetric or not)

In addition, Antares gives the possibility to improve the model through various linear constraints on either hourly, daily or weekly power flows:

- This allows to have a more realistic modeling of the behavior a meshed AC system (OPF using the classical DC approximation)
- This generic constraint editor opens also a straightforward access to many different “specific” modeling features (pumped storage stations, transmission outage simulator,…)
- Besides, interconnections can be assigned hurdle costs: these may either represent an actual right –of-use, be a simplified way to account for the cost of losses, or simply put a barrier against power exchanges with very low profitability



Two main options are offered to model the uncertainties bearing (at the hourly time-step) on load and renewable energies generation assumptions:

- Use of a wide range of ready-made time-series based on historical or forecast data

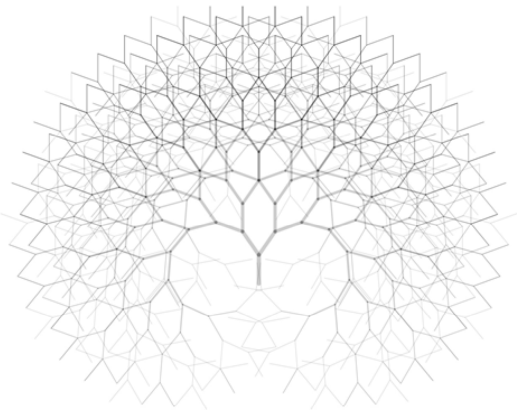
- Use of time-series generated by built-in dedicated modules:
    - Either providing these modules with known random variables multivariate parameters (densities, cross-correlations, auto-correlation parameters)
    - Or using the specialized time-series analyzer module to assess said parameters (starting from a small set of available ready-made time-series)

Statistic laws available to model time series : Uniform, Normal, Log normal, Beta, Gamma and Weibull.

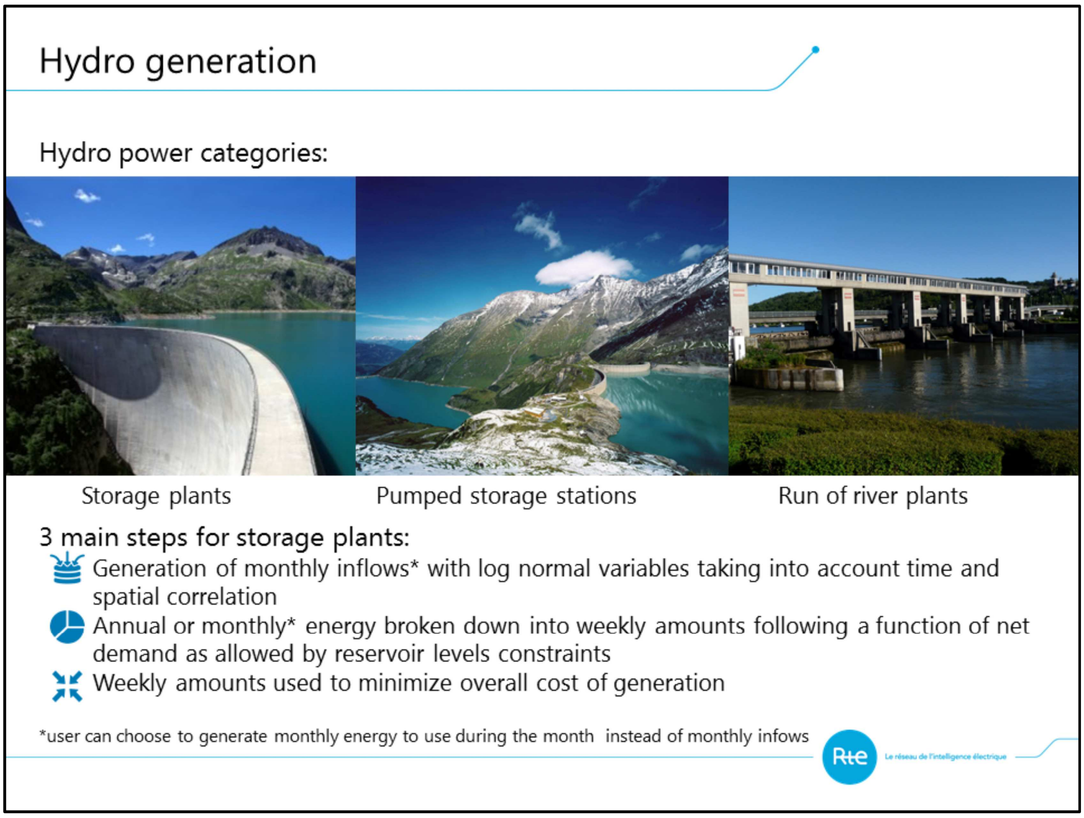
Demand-side management

Antares allows to either:

- Use ready-made hourly time-series for load modulations
- Or define specific models based on virtual assets (hydro or thermal) and virtual constraints

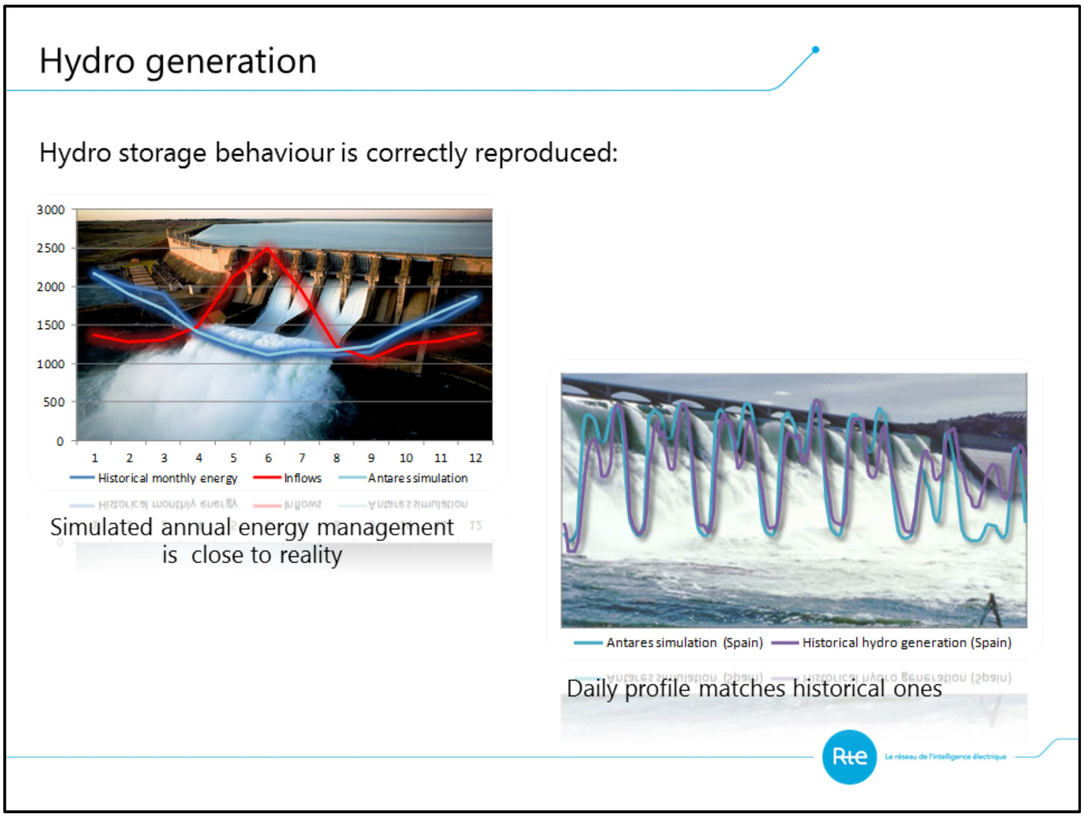


Antares allows to use an hourly pre-computed time-series for load modulation.
This model is a good choice when modeling demand-side management in response to tariff signals but cannot model other signals (activation by TSO or demand-side management actors)
For those type of demand-side management, RTE uses thermal or hydro assets modeling and add some constraints (for example maximal energy activated)



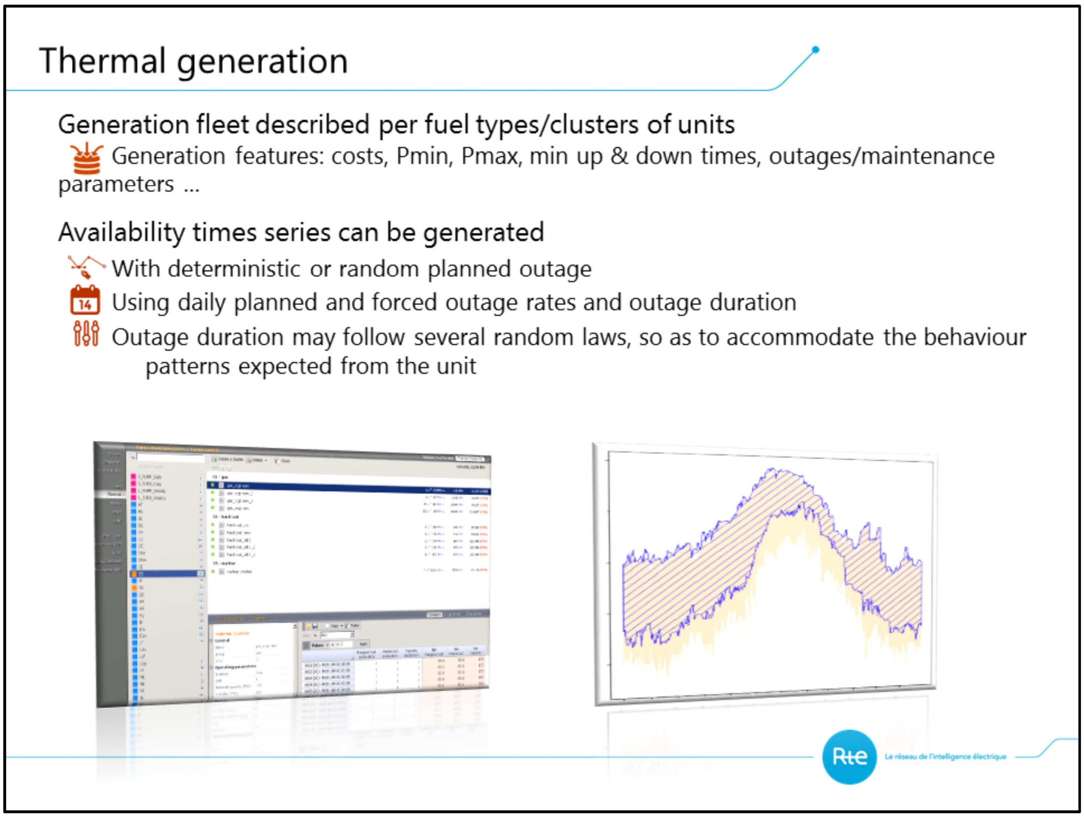
(a) Run-of-River plants
Power delivered depends (mainly) on rainfall
(b) Storage plants (inc. pondage)
Power delivered depends on rainfall & economic data
(c) Pumped storage stations
Power delivered depends on economic data

Hydro ressources management in the Antares MC simulator is based on hourly time-series for plants (a) and daily time-series for plants (b) . In both cases
it is possible to use either a ready-made set or to have it built by a dedicated generator.
For plants (c) , it is possible to use either a ready-made hourly curve or to model explicitly the operation of a PSP facility



Modeling a realistic behavior of hydraulic generation is both complex and a key-point to the supply-demand balance, especially in a context of important intermittency of wind and solar generation. The flexibility brought by hydraulic units and its impact on the unit commitment can change the valuation of network, generation and demand-side investments.

Studies carried out with Antares provide a very realistic point of view on how water is used to decrease the overall thermal production costs.



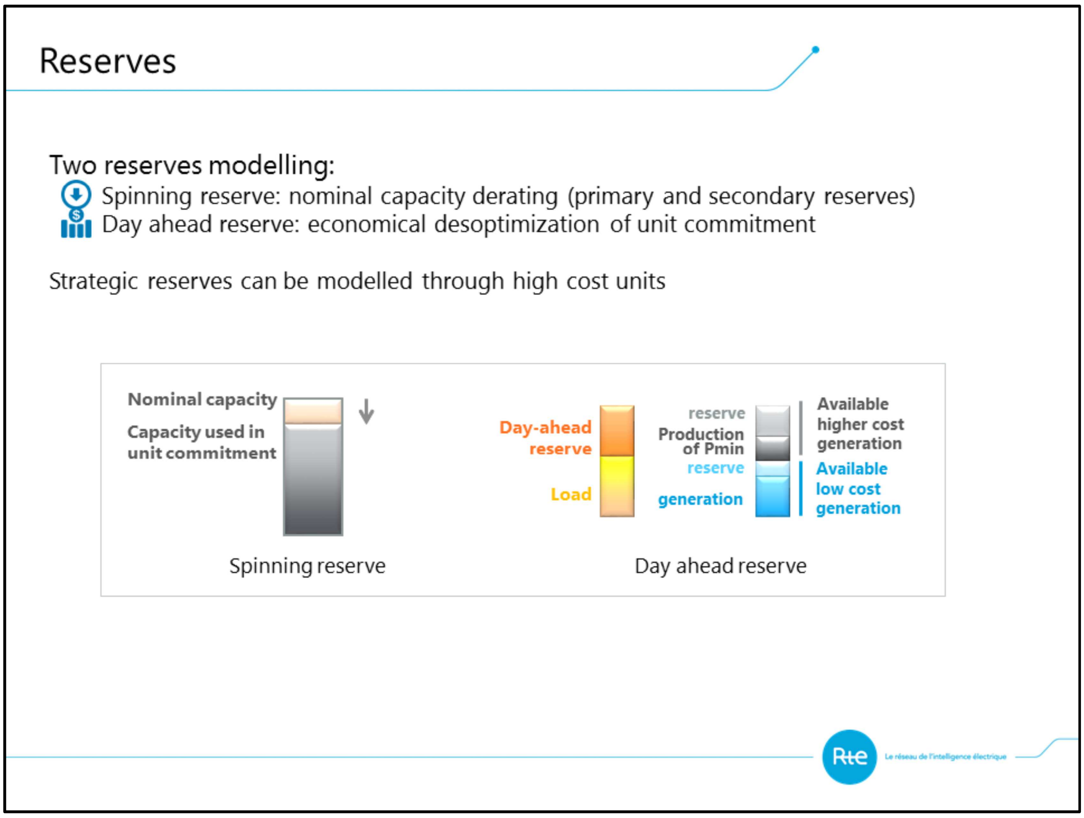
List of thermal units features

Physical characteristics :

- Nominal capacity (hourly variability available)
- Must-run as well partial must-run status (some or all of the power generated traded outside the regular market)
- Minimum stable power (hourly variability available)
- Minimum up time
- Minimum down time,
- Reserve participation
- CO2 emissions
- Forced outages parameters (frequency and duration distribution pattern, adjustable throughout the year) (data used by the built-in time-series generator)
- Planned outage parameters (frequency, duration, lower and upped bound of the number of units in maintenance)

Economic parameters :

- Marginal cost (hourly variability available)
- Market bid (hourly variability available)
- Fixed-cost (so-called No-Load heat cost)
- Start-up cost
- Spread to model price volatility



Several options are offered to describe the contribution of each unit to different kinds of operating reserves. The two main ones are the “spinning reserve” parameter, which represents the contribution of each unit to the power-frequency regulation loop, and the “day-ahead” reserve, which materializes upwards margins that have to be available within 24h to accommodate special operation conditions. Day-ahead reserves are taken into account in the assessment of the optimal unit-commitment, prior to the final determination of the optimal scheduling plan (from which they are removed)

In addition , strategic reserves may be defined as units activated to respond to adequacy issues in a specific area (hence, not activated to mitigate curtailments elsewhere). This is usually achieved by using interconnection hurdles costs tuned along with high cost “strategic” units such that :

Strategic unit Market bid + hurdle cost > VOLL (Value of Lost Load) in remote areas
Strategic unit Market bids < VOLL of the local area

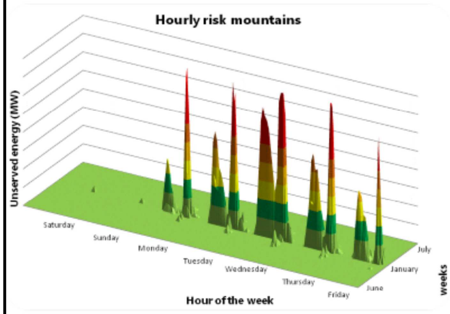
Main results

- ANNUAL INDICES
- HOURLY HEATMAPS
- HOURLY BALANCE MOUNTAINS
- DAILY DISPATCH STACKS
- NODAL ELEMENTARY RESULTS
- INTERCONNECTION ELEMENTARY RESULTS

Outputs

Easy to configure

- Results filter
- Time data aggregation from annual to hourly
- Spatial data aggregation



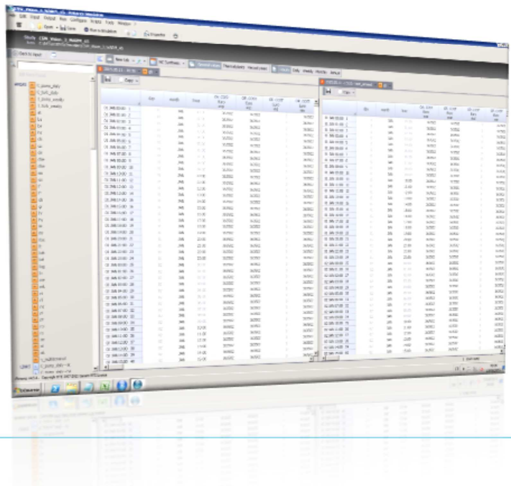
ADEQUACY	zone A	zone B	zone C	zone D	zone E	ALL
Loss of load probality (%)	6,67	0,94	24,9	0,00	0,00	27,6
Loss of load duration (hours)	0,26	0,02	2,51	0,00	0,00	2,69
Loss of load expectation (GWh)	0,11	0,03	4,90	0,00	0,00	5,03

ECONOMICS	zone A	zone B	zone C	zone D	zone E	ALL
Exc Balance EB (TWh)	-12,1	30,3	-1,1	-12,4	-4,7	0,0
Gen Cost GC (M€)	1465	10810	6908	2558	180	21922
CO2 (M tons)	22	432	28	74	2	557

Outputs

Output interface allowing

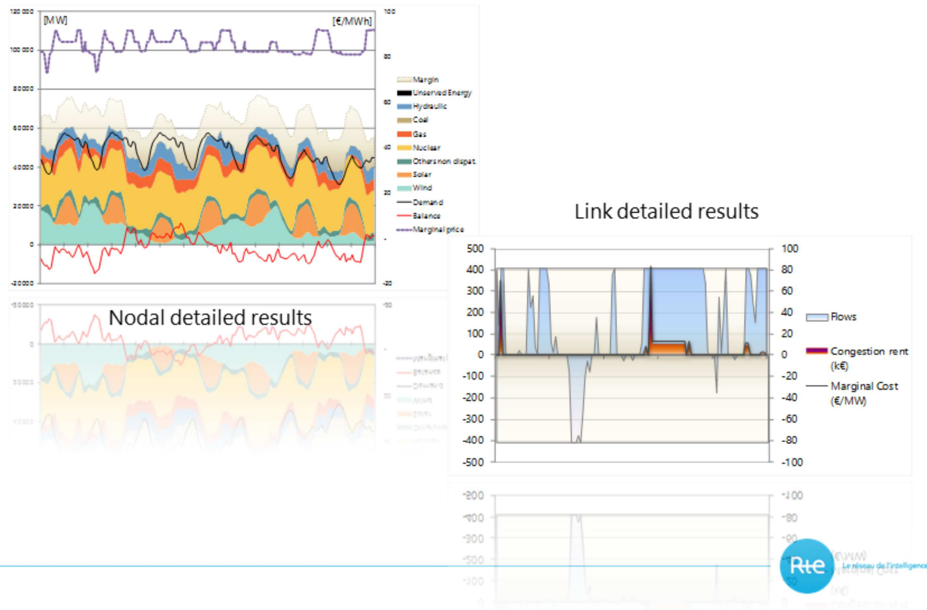
- Easy handling of all categories of output data
- Comparisons of either synthetic or detailed results



Rte Le réseau de l'intelligence électrique

Outputs

Exhaustive list of output indicators



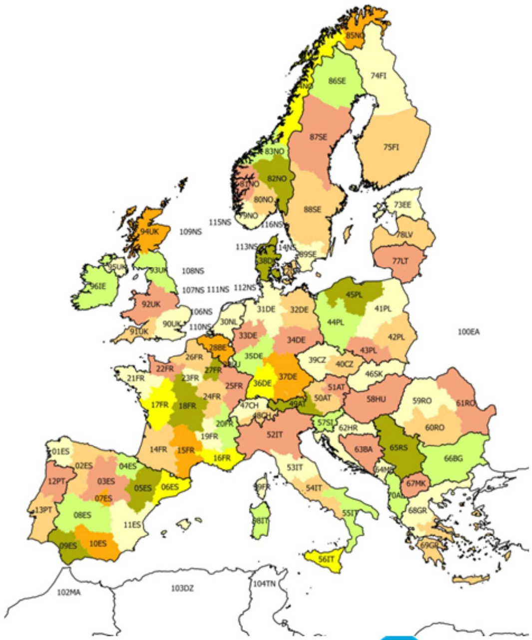
Outputs give many different views of the results, from fully detailed (each variable for each hour of each scenario) to more or less aggregated indexes (average , standard deviation, extreme values of either hourly, daily, weekly, monthly sub-totals, for each area as well as for larger regions)

Likewise, results regarding interconnections are displayed with a wide range of possibilities

Outputs

Text file easy to import in:

- Spreadsheet
- Data mining software
- Cartography software



Le réseau de l'intelligence électrique


References
REFERENCES
E-HIGHWAYS
TYNDP
ADEQUACY STUDIES
CAPACITY MARKET STUDIES
OTHER STUDIES
Rte

References

Rte

elia

MAVIR

amprion

CENACE
CENTRO NACIONAL DE CONTROL DE ENERGÍA

ekc

HIGHWAY 2050

Adequacy studies

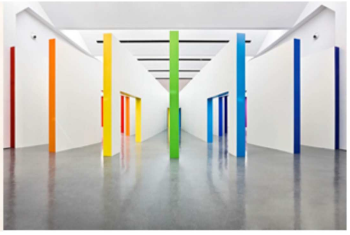
Tool for French adequacy study since 2011:

- Adequacy indicators and energy mix for year N+1 to N+5 and N+15
- About 20 visions studied, each with 1000 Monte Carlo year
- Essential input in deliberations about Energy transition

Tool for Belgian adequacy study since 2014

New tool for Mexican, Hungarian and Serbian adequacy studies

Capacity market studies



RTE uses Antares for:

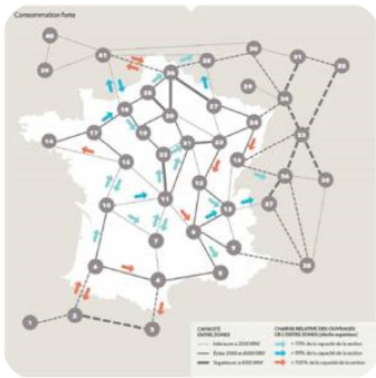
- Choose of several parameters of the mechanism
  - Contribution of importation to national adequacy
  - Contribution of storage unit

- Internal studies about different options of market design
  - How many certificate will receive each type of unit ?
  - How importation will participate to national adequacy in differents options of load curtailments sharing between countries ?

Others RTE studies

Examples of studies:

- French zonal model in the process for network development
- Smartgrids projects assessment
- Generation capacity optimization



French zonal model:
France is divided into several areas and an equivalent network is defined between those areas.
This kind of studies therefore requires downscaling for supply-demand hypothesis as well as for grid modeling (capacity and “impedance” of the links).
The purpose of the French zonal study is typically to capture the directions taken by electricity flows and their day/night, seasonal amplitudes.
This information is used in complement to other network studies devoted to the general and strategic issue of the national network operation and expansion

Smart grids projects assessment:

Prospective studies may help to assess the impact of the introduction of new smart grid projects : valuation, changes in the use of thermal units, new possibilities for inserting more renewable energy generation…

Generation expansion:

Antares is also used to gather sound views regarding electricity generating fleets perspectives for distant timelines studies (2030 – 2050).

ENTSOe studies

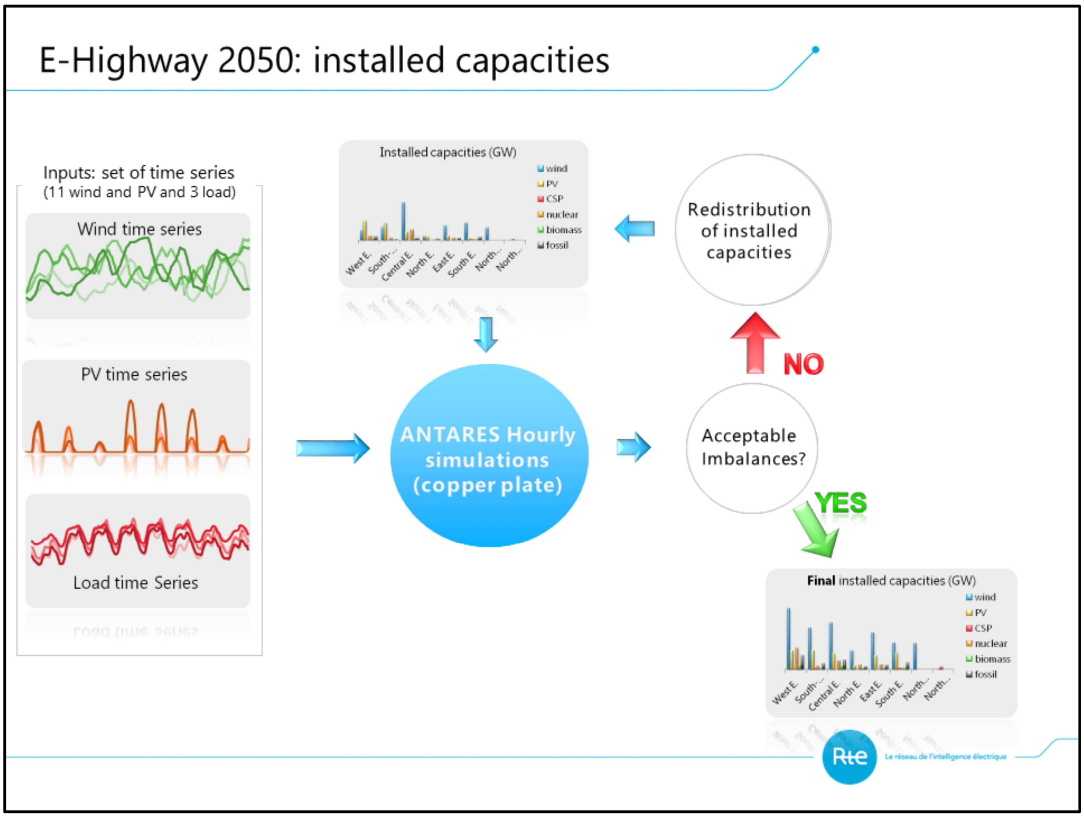
Antares is used by Elia and RTE in ENTSOe studies:

- TYNDP
- PLEF
- MAF

Ten Year Network Development Plan (TYNDP):
Long-term network development plan allows transmission system operator (TSO) to tailor grids to the evolution of demand and generation, securing an affordable supply of energy for customers in the next decades. Since 2009 the European legislator has tasked ENTSO-e with the delivery of a European network development plan which builds on national plans and includes specific regional investment plans. The aim of this annual study is to have a European approach to grid planning and to ensure consistency and cost-efficiency.

PentaLateral Energy Forum (PLEF):
PLEF is an intergovernmental initiative (BE-NE-LUX-FR-DE-AT-CH) with two major workstreams: market integration (flow based market coupling) and security of supply (adequacy studies by TSOs and development of a common approach to security of supply in the region).

Mid term adequacy forecast (MAF):
This ENTSO-e study consists in a Pan-Europe an probabilistic assessment of adequacy to better account for the risks to security of supply and the need of flexibility as the European power system moves towards higher level of RES. It helps highlighting the contribution of electricity interconnectors to national adequacy at times of potential scarcity.



The e-Highway2050 scenarios have been defined following a top-down approach: from European to cluster level.

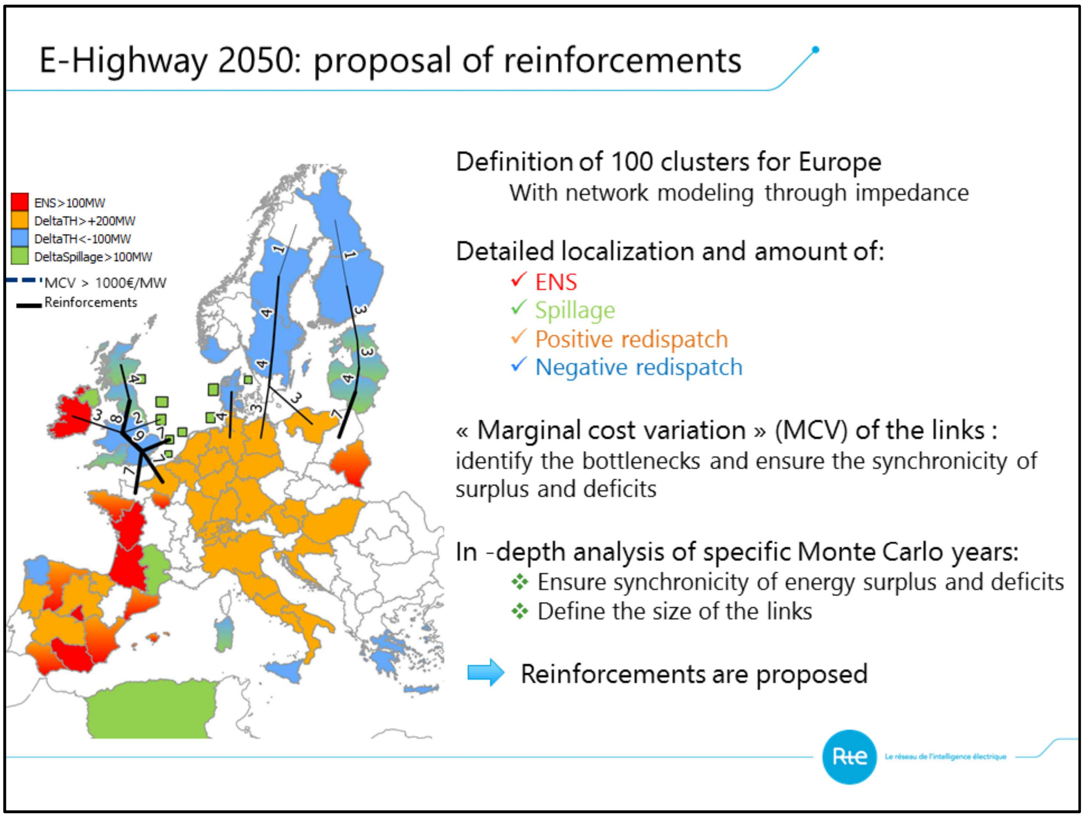
Before defining installed capacities:

- five "extreme but realistic" scenarios were identified and described verbally. For each of them, a European energy mix was defined. For more details see D1.2 of the e-Highway2050 project (http://www.e-highway2050.eu/results/) : "*Structuring of uncertainties, options and boundary conditions for the implementation of EHS*".
- the annual demands per country were calculated following the assumptions of each scenario (economical growth, number of electric vehicles…). Demand time series were built from historical time series and typical consumption patterns of new uses.

Generation capacities were then defined in order to fulfil the targeted energy mixes while ensuring a sufficient level of adequacy (European average loss of load duration < 3 hours) in copper plate. They were located gradually: first at macro-area level, then at country level and finally at cluster level. For more details, see D2.1 of the e-Highway2050 project : "*Data set of scenarios for 2050*".

For macro area level, a first simulation is made with :
For each type of generation technology, the European required installed capacity is distributed between the different macro areas thanks to "distribution keys". These distribution keys are scenario and technology dependent and they are computed from the demand and the generation potential of the areas (see part three for more details on their calculations for each technology). In addition, potentials per area and per technology have been defined (see part three for more details) and are used as an upper bound for the installed capacities of each area (note : potentials are not scenario dependent).

The first set of Monte-Carlo years (100, depending on the number of solar, wind and load time series) is simulated returning adequacy outputs, such as the Loss of Load Duration (LOLD). The LOLD is a quite convenient way to assess how far the system is from a reason-able adequacy. If the LOLD is higher than 3 hours, meaning that extra capacity is needed, incremental changes in installed capacities are then applied in the algorithm.
Simulations on ANTARES are performed again. This process is repeated until the adequacy criteria (LOLD<3h) is valid and unsupplied energy is low. Once all technologies have been increased, some storage is added to the system. Finally, if every bound has been reached and adequacy is still not met, peaking units are added at the end. These units are used a few hours per year but are necessary for adequacy. They represent either peaking thermal units or DSM. They are modelled in Antares as thermal units with high costs.



Once installed capacities have been defined at the cluster level (100 territorial clusters for modeling Europe in this project) Antares simulation runs yield:

- ✓ Energy Not Supplied (ENS)
- ✓ Spilled (or wasted) Energy (RES than could be generated but neither used nor stored
- ✓ Positive redispatch required to accommodate transmission limits)
- ✓ Negative redispatch required to accommodate transmission limits)

The previous indexes as well as some others (such as the marginal overall system cost sensitivity to 1MW transmission capacity upgrade here and there) helped the project team to identify bottlenecks and suggest mitigation measures (including backbone reinforcements)

Conclusion

ANTARES is a Monte-Carlo software for power systems analysis…

- Sequential
- Multi-areas
- With a time span of one year
- With a time resolution of one hour

Designed for

- Generation / Load balance studies (Adequacy)
- Economic assessment of Generation projects
- Economic assessment of Transmission projects

Not designed for

- Studies of large systems without simplification
- All technical studies