Grid operation-based outage maintenance planning

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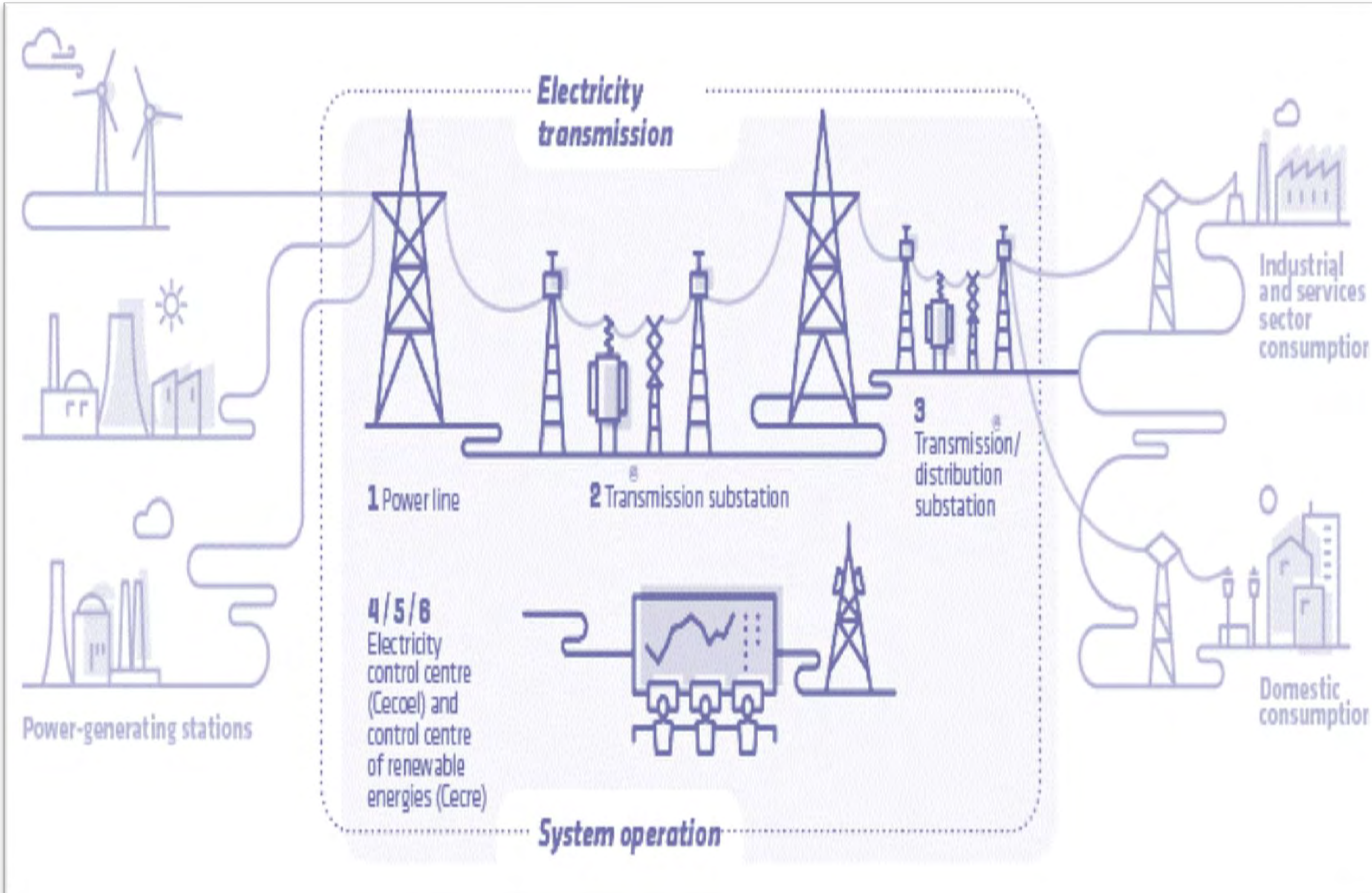
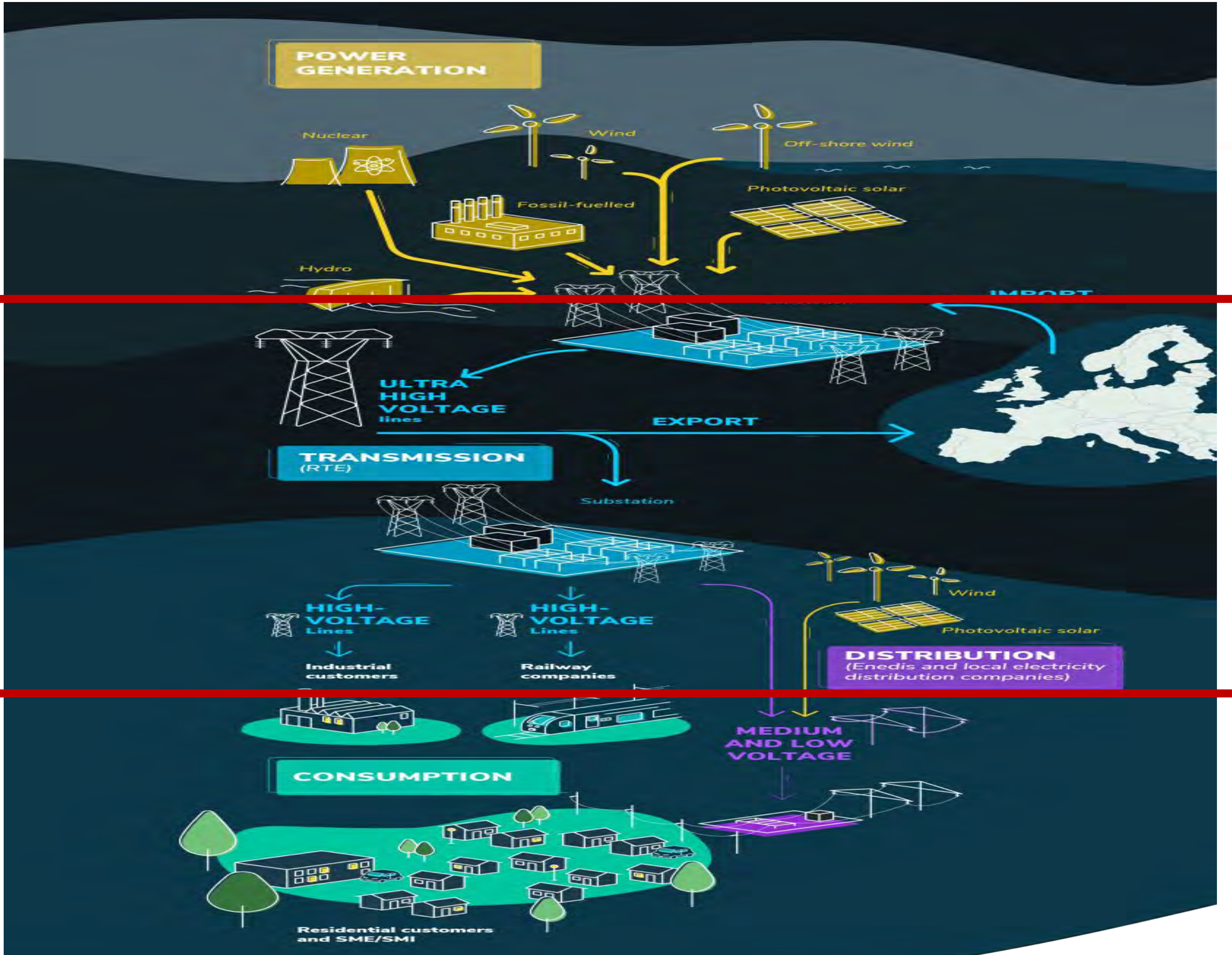
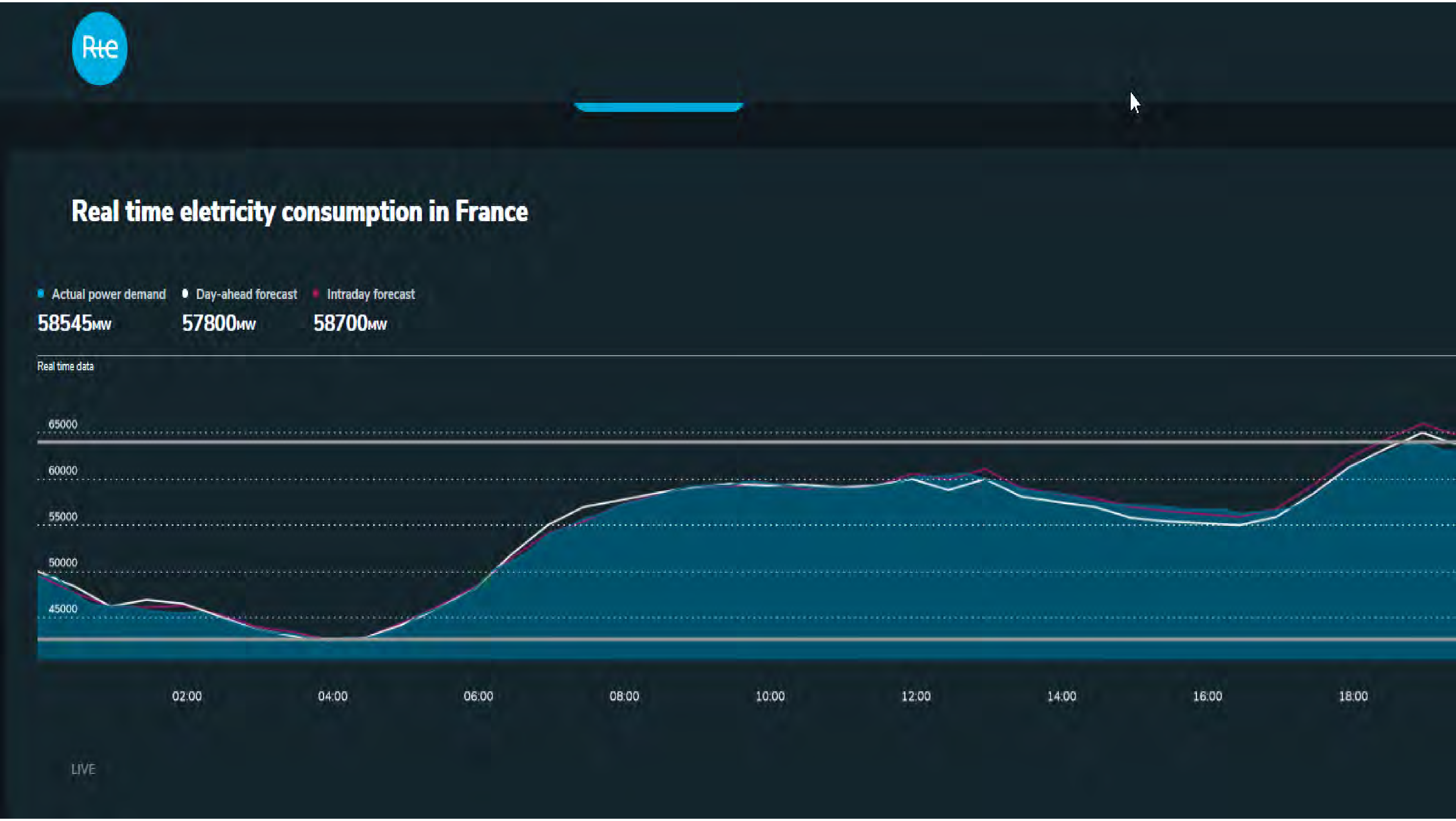
Electricity transmission system operator



https://www.ree.es/en/about-us/business-activities/electricity-business-in-Spain

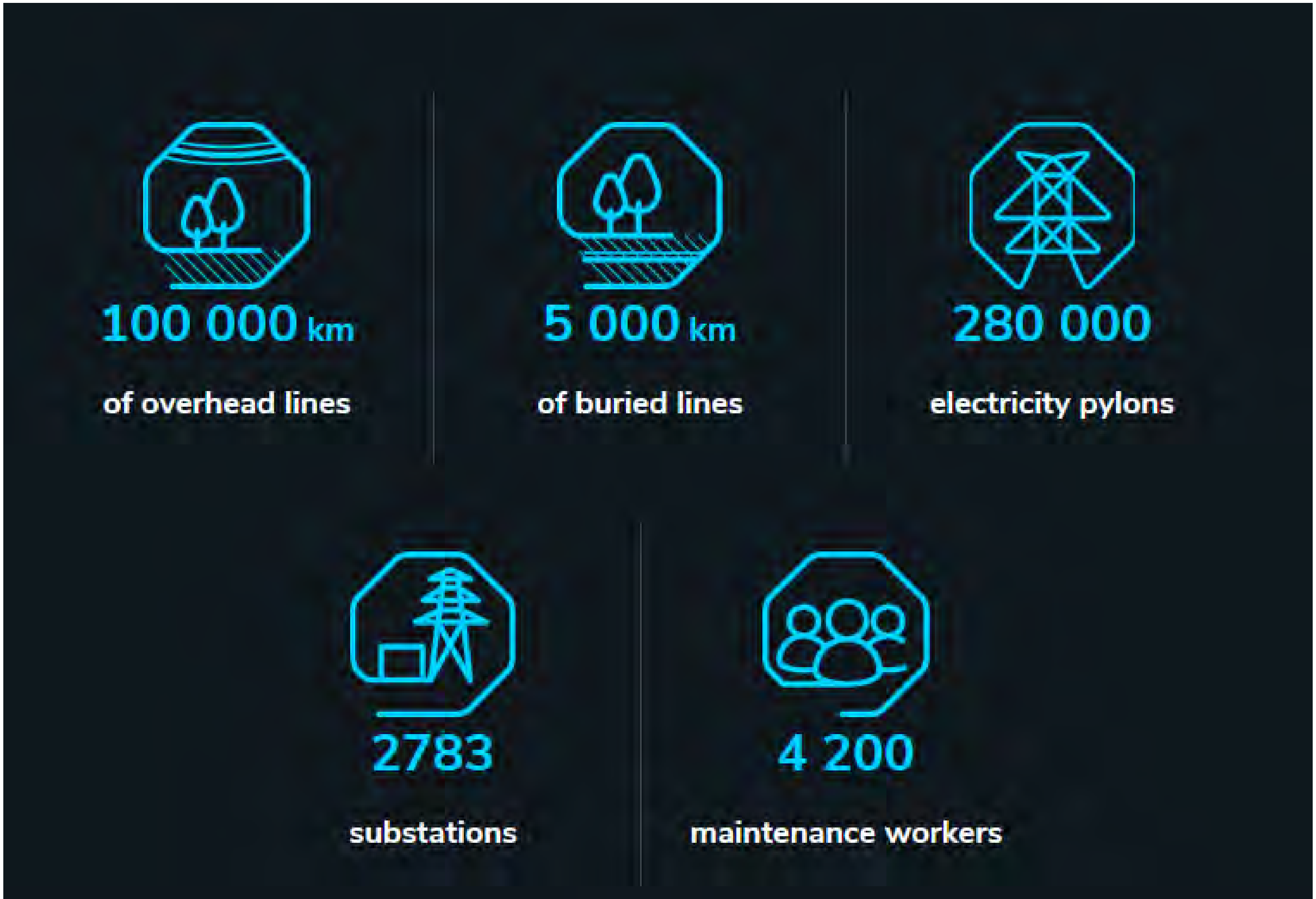

POWER GENERATION
Nuclear
Wind
Off-shore wind
Fossil-fuelled
Photovoltaic solar
Hydro
IMPORT
ULTRA HIGH VOLTAGE lines
EXPORT
TRANSMISSION (RTE)
Substation
HIGH-VOLTAGE Lines
Industrial customers
HIGH-VOLTAGE Lines
Railway companies
Wind
Photovoltaic solar
DISTRIBUTION (Enedis and local electricity distribution companies)
MEDIUM AND LOW VOLTAGE
CONSUMPTION
Residential customers and SME/SMI

RTE: meeting the demand



RTE key figures

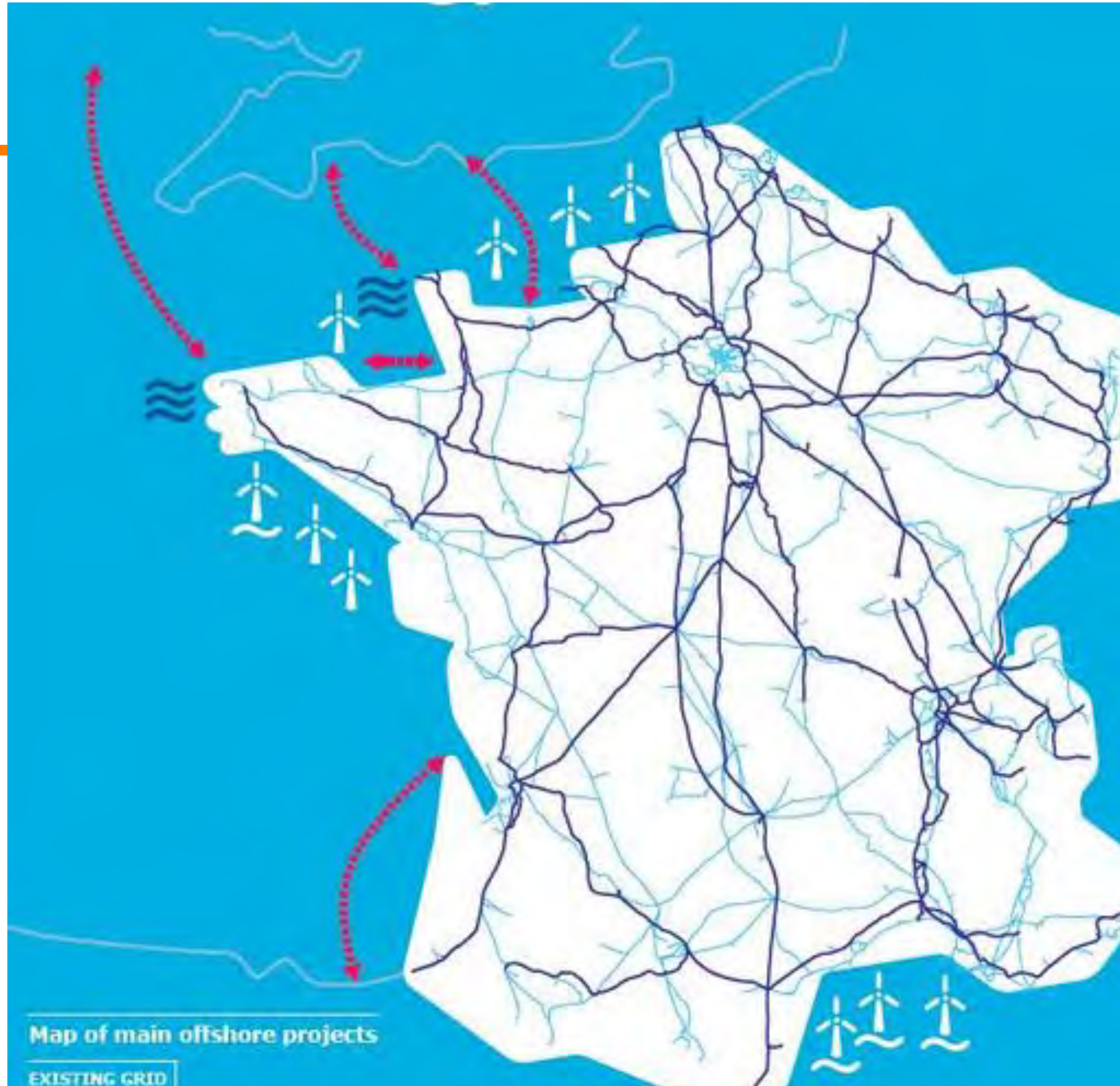
RTE maintenance



RTE maintenance tasks

RTE maintenance tasks

Network



https://www.researchgate.net/publication/273509890_Optimization_of_Cascade-

Maintenance planning under uncertainty

The three- step approach of RTE:

- **RISK**
  - Calculate the risk of each intervention under each scenario

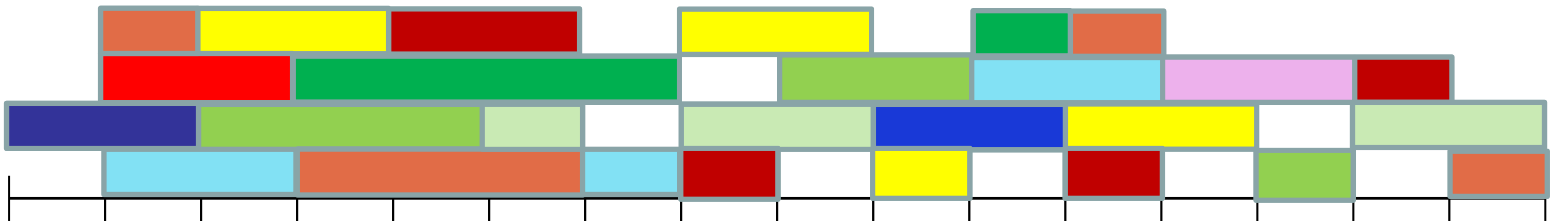
- **PLAN**
  - Assign interventions to periods minimizing a risk measure

- **VALIDATE**
  - Check is the plan is adequate

Planning the interventions

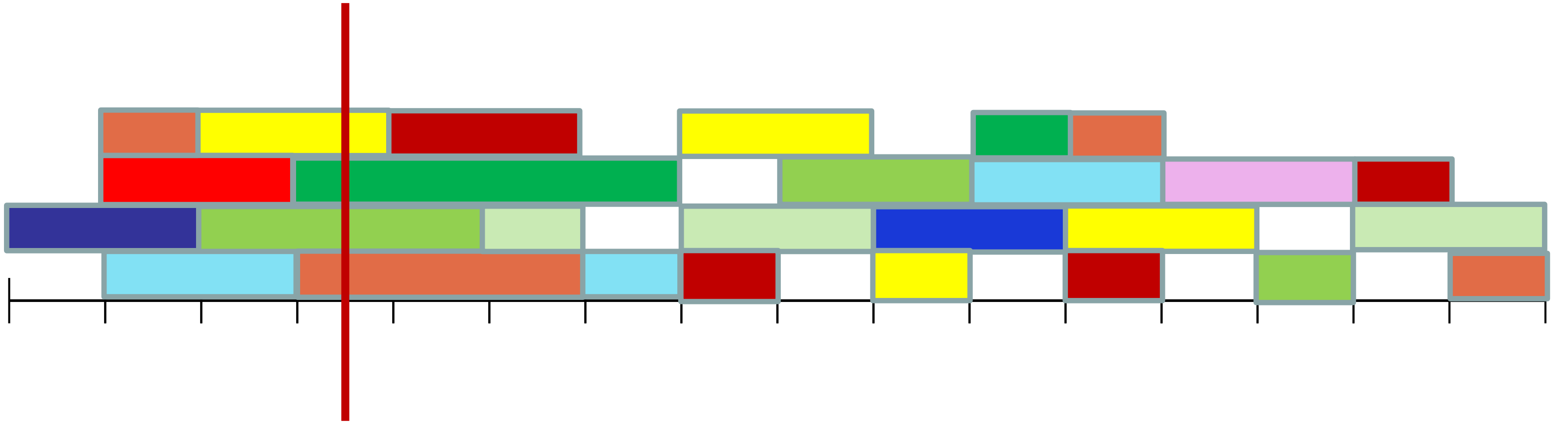
Interventions: tasks involving shutting down parts of the network

Assign interventions to periods in the planning horizon



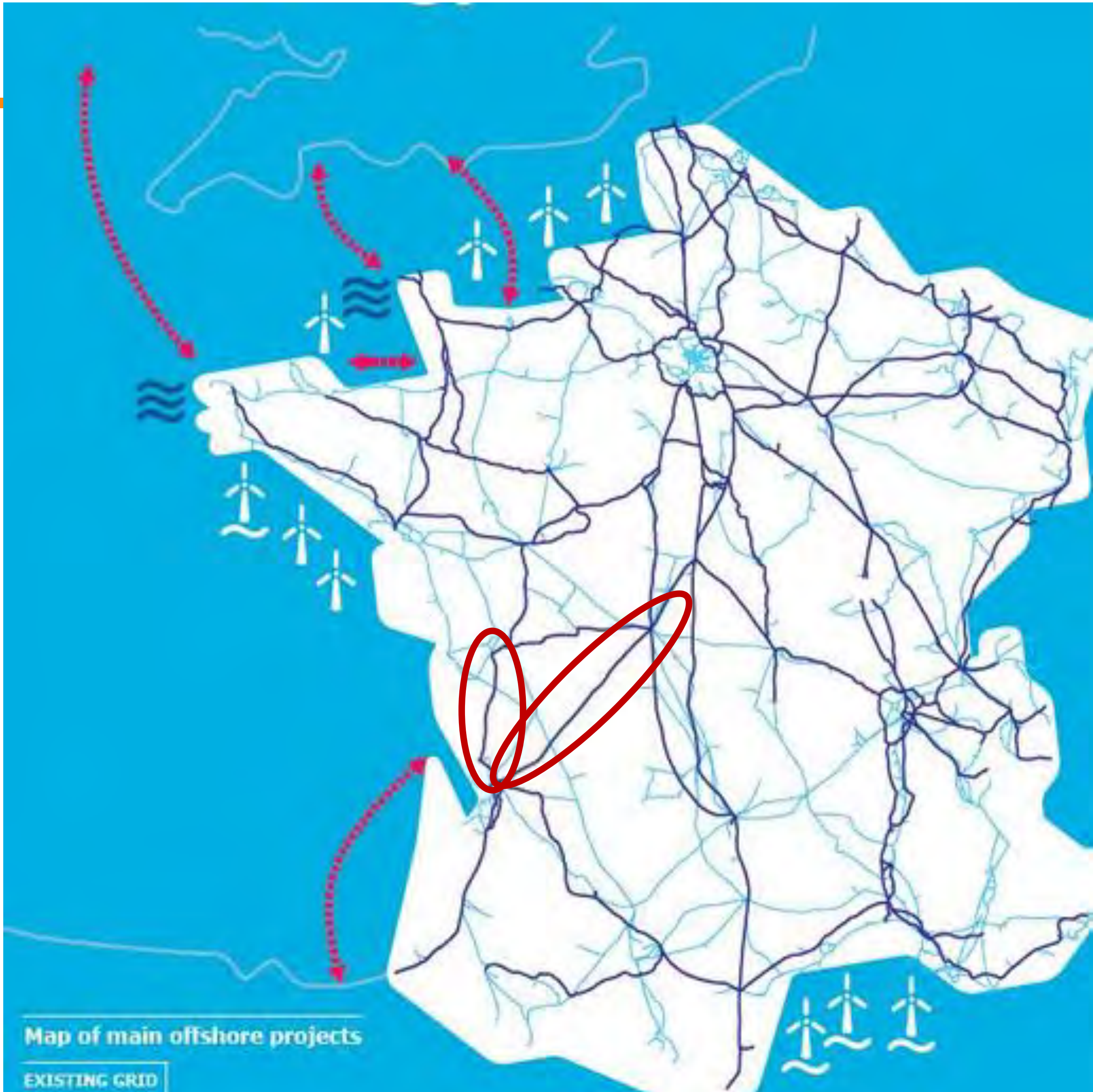
Constraints

- All interventions must be planned within the time horizon
- No-preemption: once started, the intervention cannot be interrupted
- Resource consumption: between the limits



Exclusions

pairs of interventions that cannot be done simultaneously



Exclusions

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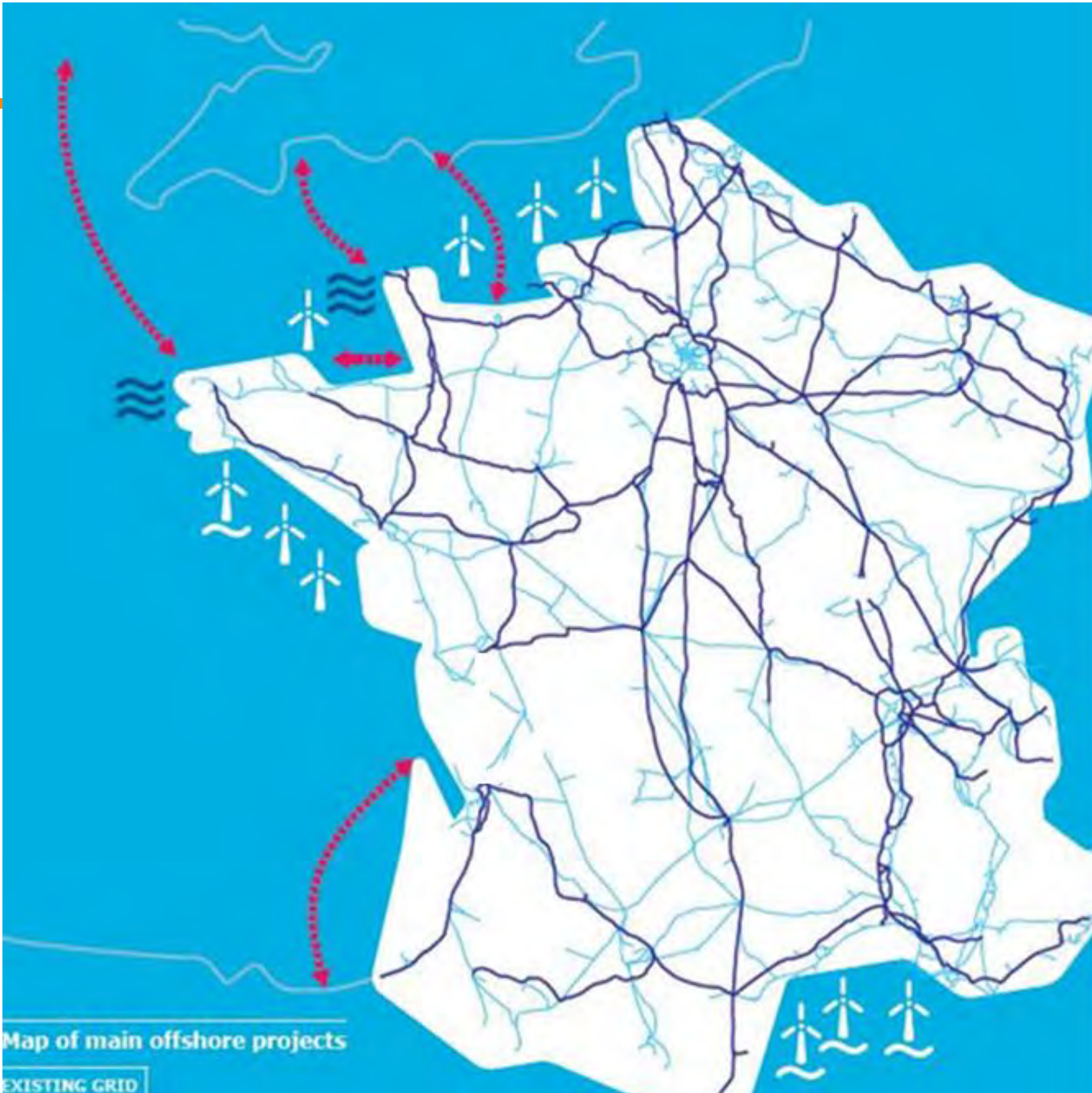
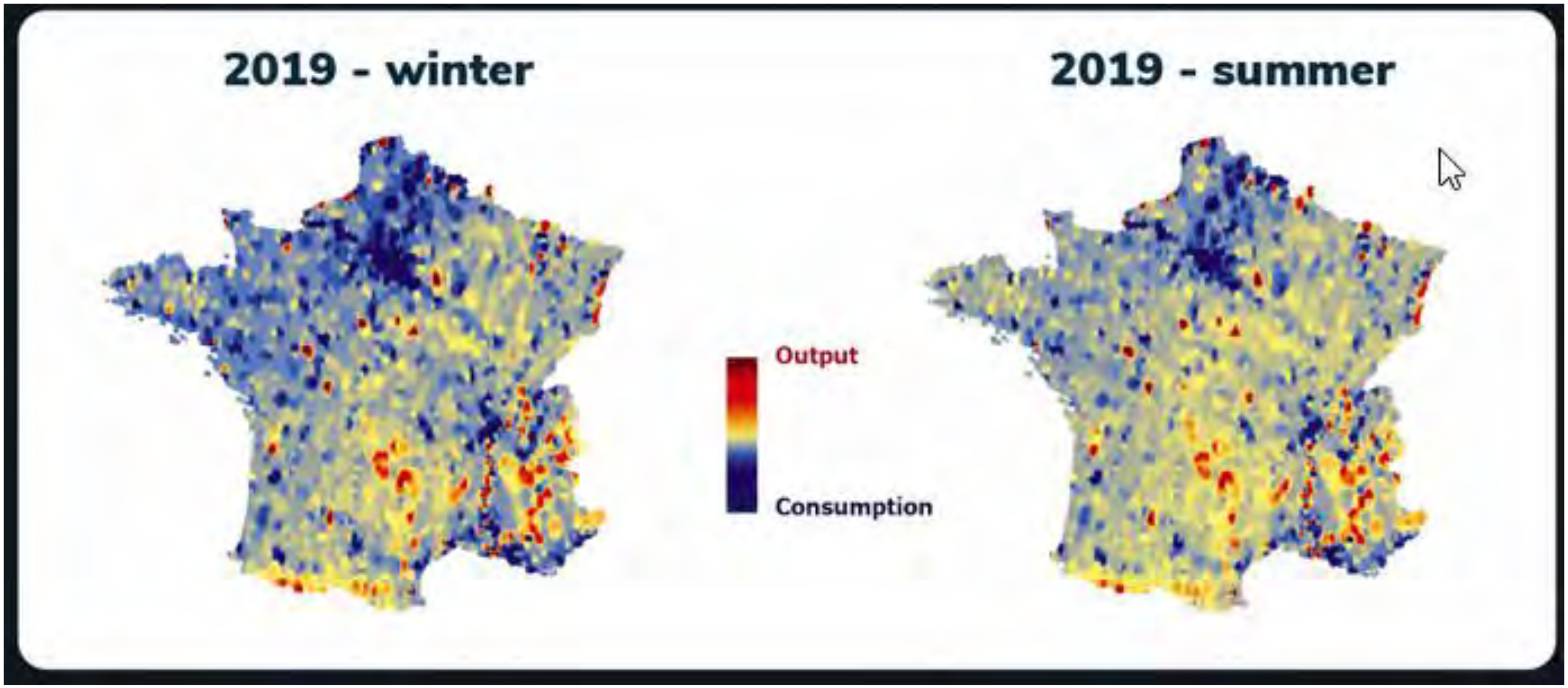


Resources and exclusions depend on time



https://www.researchgate.net/publication/328602901_Resilience_of_electricity_grids_against_transmission_line_overloads_under_renewable_power_injection

Measuring the risk

scenario

time period

$$risk_{i,\tau}^{s,t}$$

intervention

starting time

Mean risk cost

- Adding up all interventions in process at a given time t

$$risk^{s,t} = \sum_{i \in I_t} risk_{i,start_i}^{s,t}$$

- Taking the average over all the scenarios

$$\overline{risk}^{t} = \frac{1}{|S_t|} \sum_{s} risk^{s,t}$$

- Taking the average over all time periods: **Mean risk cost**

$$obj_1 = \frac{1}{T} \sum_{t} \overline{risk}^{t}$$

Expected excess

- Calculate the quantile of the risk distribution at a time t over the scenarios

$$Q_\beta^t = Q_\beta\left(\left\{risk^{s,t}\right\}_{s\in S_t}\right) \qquad \text{(for instance, } \beta = 90\%)$$

- Define the excess as the difference between quantile and average risks

$$Excess_\beta(t) = \max\left\{0,\ Q_\beta^t - risk^{s,t}\right\}$$

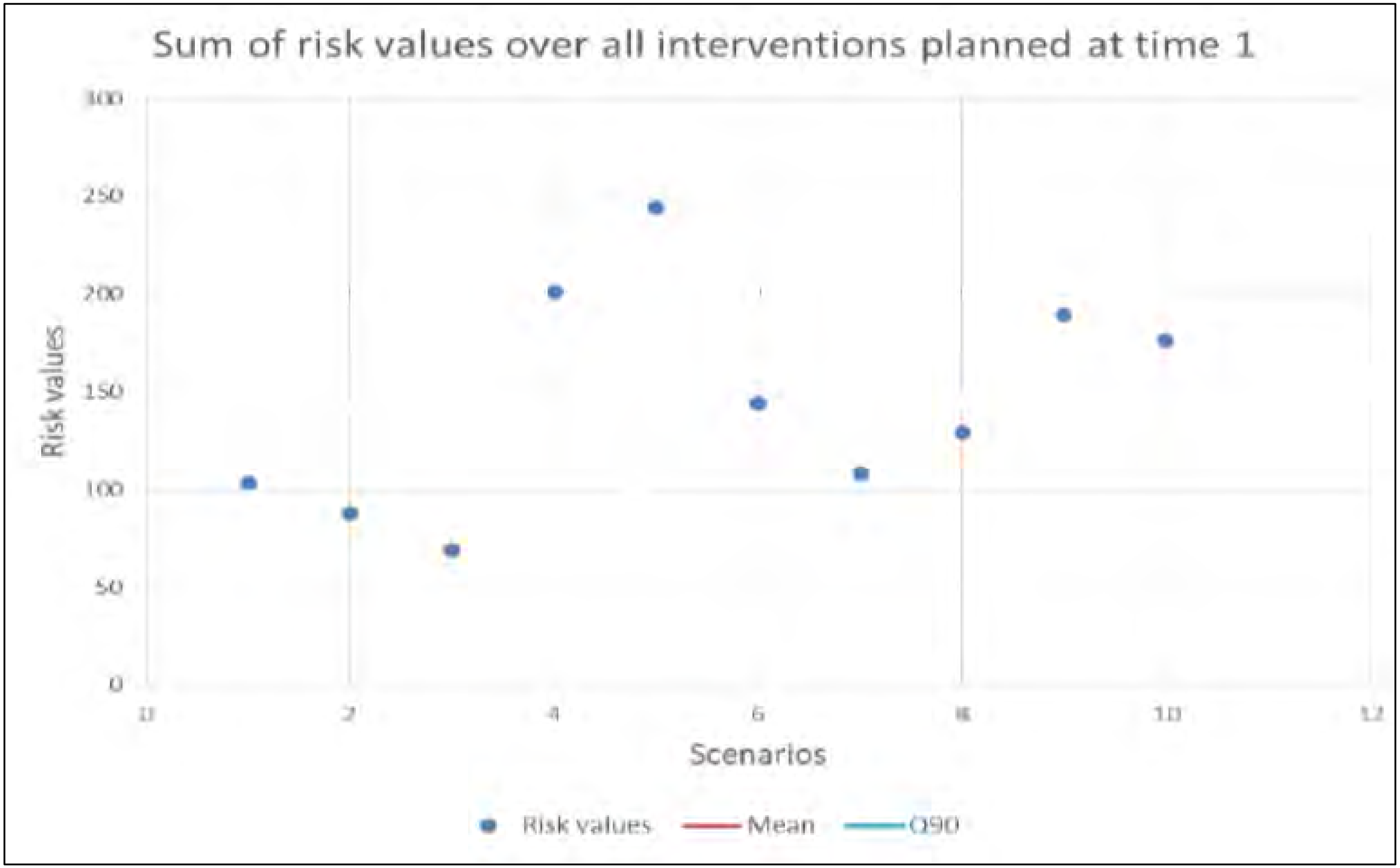
- Taking the average over all time periods: **Expected excess**

$$obj_2 = \frac{1}{T}\sum_t Excess_\beta(t)$$

(quantile: x is the smallest value such that $\Pr[X \le x] \ge \beta$ *)*

Explaining the excess

Time 1: 10 scenarios,
3 interventions whose risks are added for each scenario



Explaining the excess

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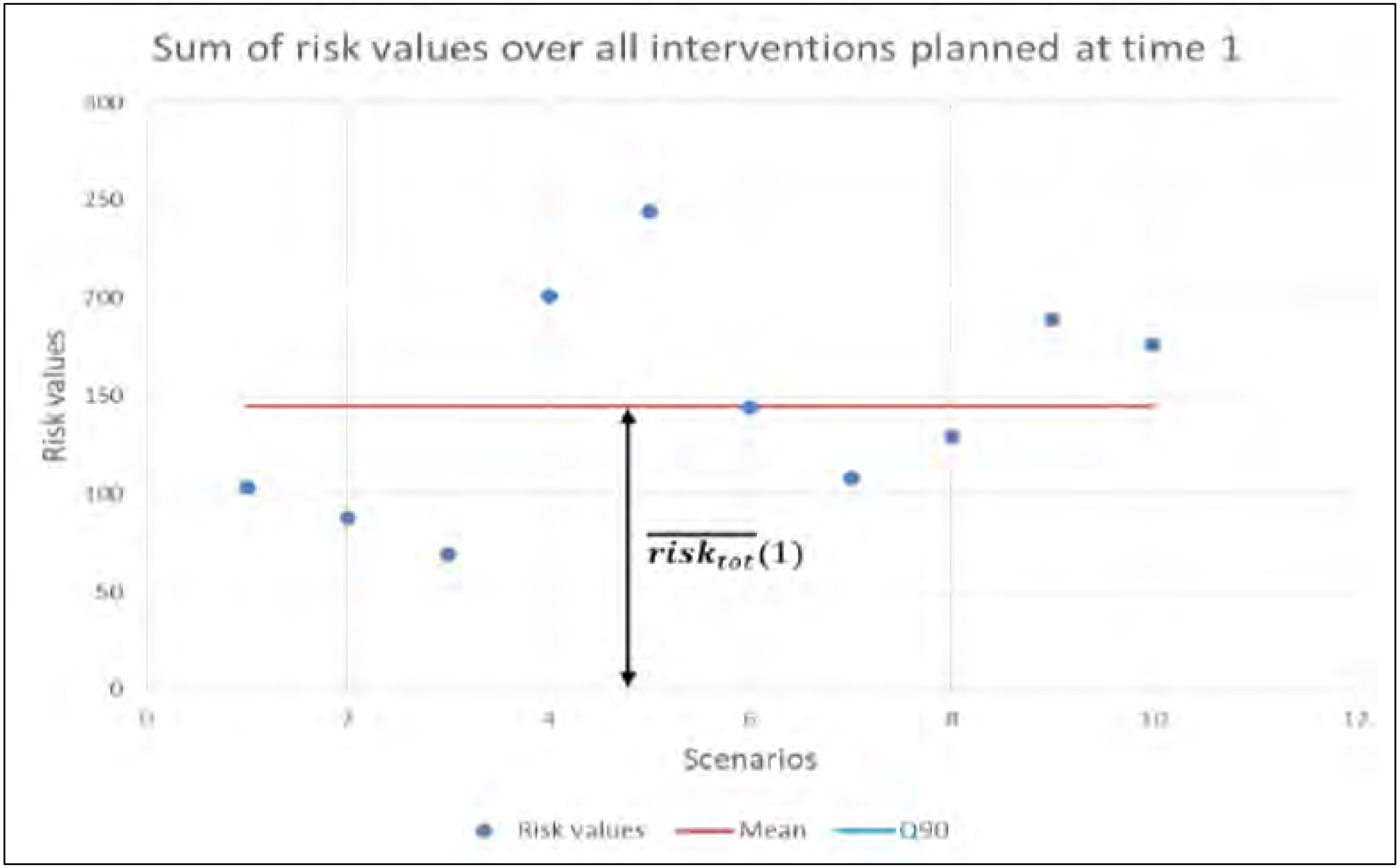

Explaining the excess

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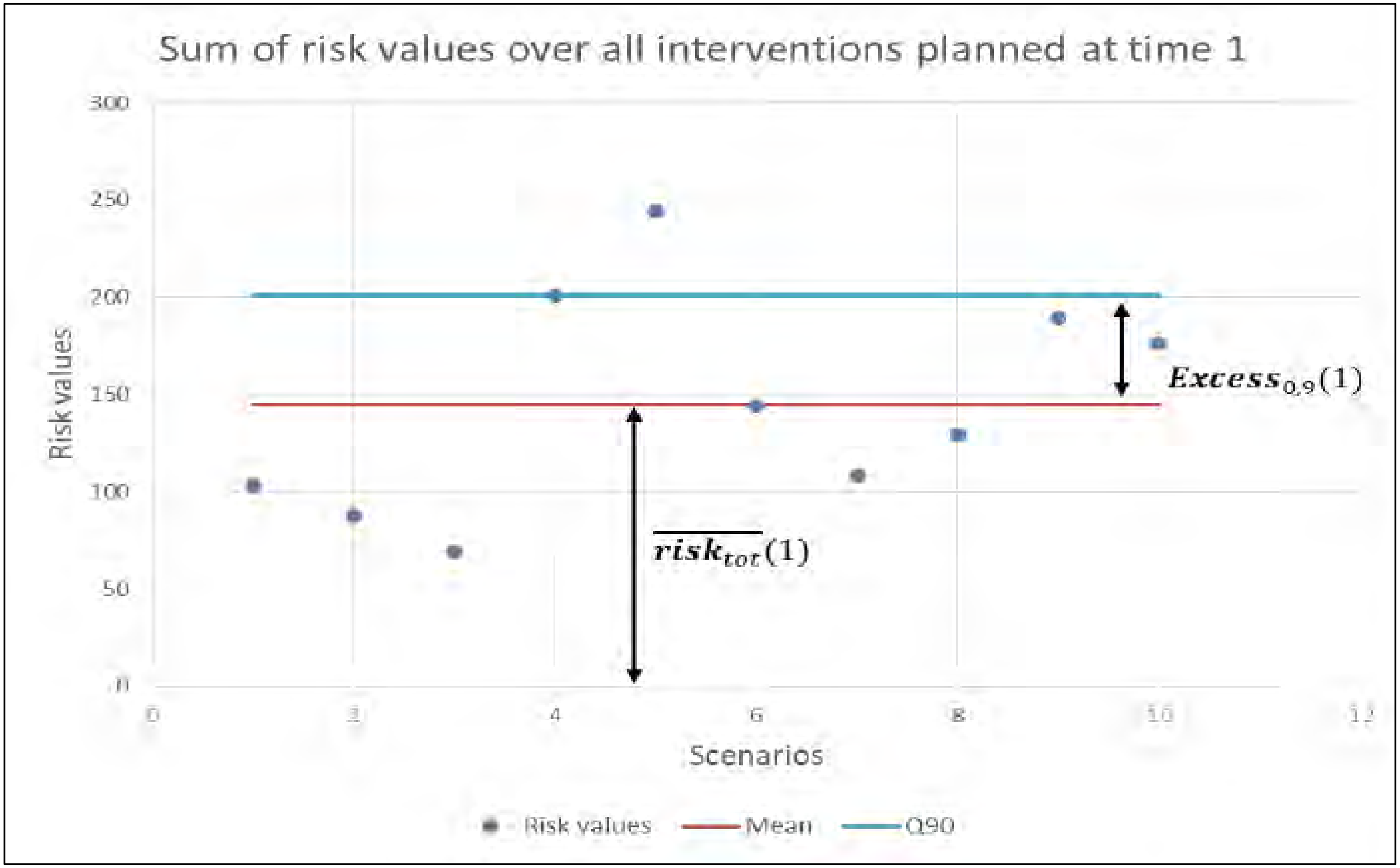


Combined objective function

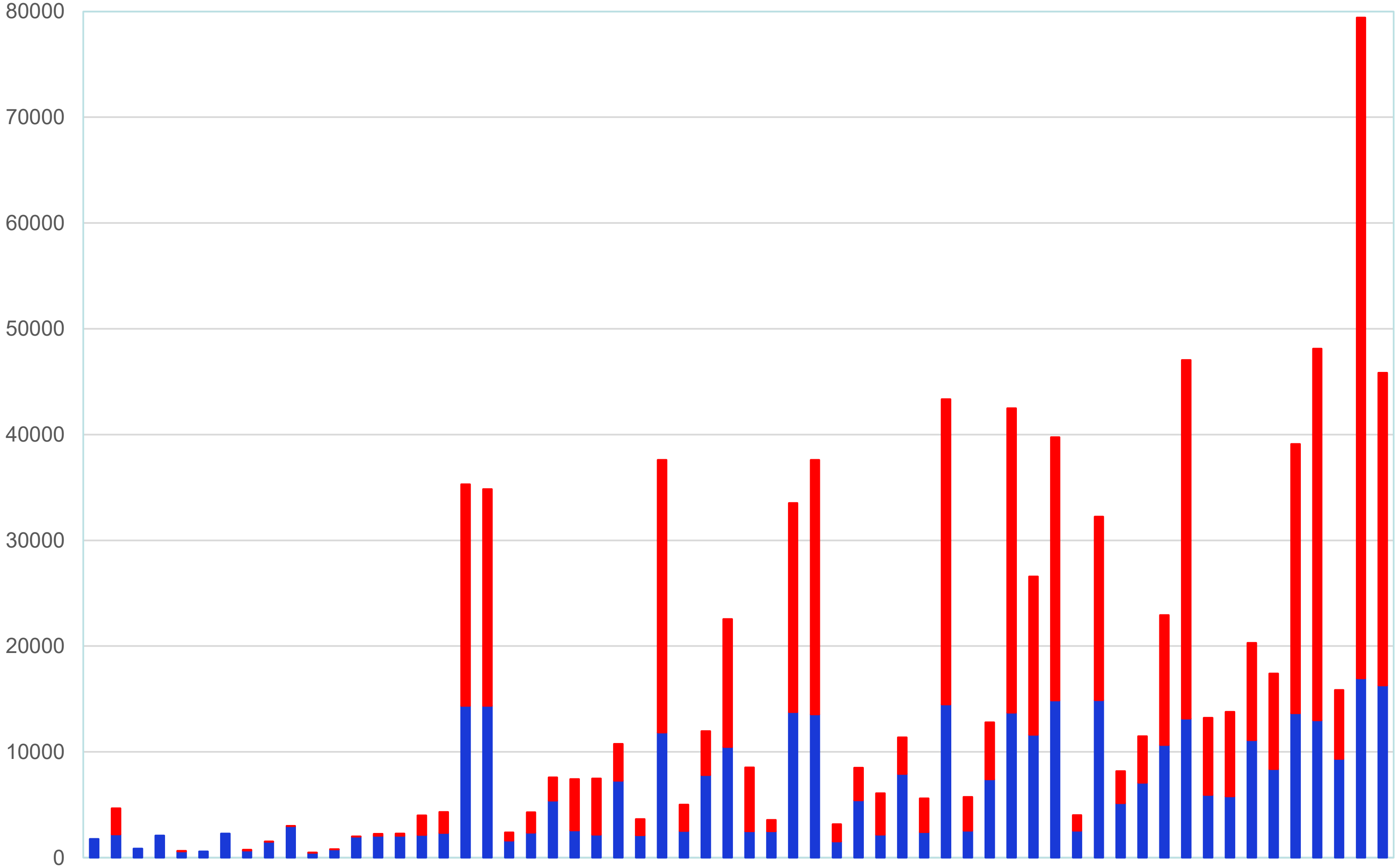
$$OBJ_{\beta} = \alpha \; obj_1 + (1-\alpha) \; obj_2$$

mean risk

excess
(risk variation)

relative weight

Is the excess really important?



Algorithmic scheme

1. Obtaining an **initial solution** using a GRASP algorithm
2. Obtaining a **pool of good solutions** by using integer linear models
3. **Improving** the solutions with a VND algorithm
4. **Intensifying** the search in the neighbourhood of the best solutions

GRASP algorithm to obtain an initial solution

- **Constructive algorithm**
  - Add one intervention at a time from the ordered list
    - Highest minimum risk
    - Highest regret (difference between lowest and second lowest risk)
    - Maximum percentage of resource consumption

- **Randomization**
  - Sample Plus Greedy (select randomly a number of intervention and choose the first in the ordered list)

- **Improvement**
  - VND algorithm

Model 1: considering only risk

$$x_{it} = \begin{cases} 1 & \text{if intervention } i \text{ starts at time } t \\ 0 & \text{otherwise} \end{cases}$$

$$Minimize \quad \sum_i \sum_t risk_{it} \; x_{it}$$

$$s.t. \qquad \sum_t x_{it} = 1 \qquad \forall i$$

$$l_t^c \le \sum_i \sum_{\tau | \tau \le i \le \tau + d_{it} - 1} r_{i\tau}^{ct} \; x_{i\tau} \le u_t^c \qquad \forall c, \; \forall t$$

$$x_{it_1} + x_{jt_2} \le 1 \qquad \forall (i, j, t) \in Excl$$

$$\forall t_1 \mid t_1 \le t \le t_1 + d_{it_1} - 1$$

$$\forall t_2 \mid t_2 \le t \le t_2 + d_{it_2} - 1$$

$$(where \quad risk_{it} = \sum_{s \in S_t} \sum_{\tau | \tau \le t \le \tau + d_{i\tau} --1} risk_{it}^{s\tau} \;)$$

Model 2: adding individual quantiles

$$x_{it} = \begin{cases} 1 & \text{if intervention } i \text{ starts at time } t \\ 0 & \text{otherwise} \end{cases}$$

$$Minimize \quad \sum_i \sum_t (\alpha\, \mathbf{q_{it}} \; + \; (1-\alpha)\, risk_{it})\, x_{it}$$

$$s.t. \qquad \sum_t x_{it} \; = \; 1 \qquad\qquad \forall i$$

$$l_t^c \; \le \; \sum_i \sum_{\tau | \tau \le i \le \tau + d_{it} - 1} r_{i\tau}^{ct}\, x_{i\tau} \; \le \; u_t^c \qquad\qquad \forall c, \; \forall t$$

$$x_{it_1} \; + \; x_{jt_2} \; \le \; 1 \qquad\qquad \forall (i, j, t) \in Excl$$

$$\forall t_1 \mid t_1 \; \le \; t \; \le \; t_1 + d_{it_1} - 1$$

$$\forall t_2 \mid t_2 \; \le \; t \; \le \; t_2 + d_{it_2} - 1$$

(*where* q_{it} = sum of quantiles of risk distribution of intervention i
over the scenarios S_t in all times t in which i is in process)

Model 3: minimizing maximum risks

$$x_{it} = \begin{cases} 1 & \text{if intervention } i \text{ starts at time } t \\ 0 & \text{otherwise} \end{cases}$$

$$M_t = \text{maximum risk at time } t$$

$$Minimize \sum_t (\alpha M_t + (1-\alpha) \sum_i risk_{it} \; x_{it})$$

$$s.t. \quad \sum_t x_{it} = 1 \qquad \forall i$$

$$l_t^c \le \sum_i \sum_{\tau | \tau \le i \le \tau + d_{it} - 1} r_{i\tau}^{ct} \; x_{i\tau} \le u_t^c \qquad \forall c, \forall t$$

$$x_{it_1} + x_{jt_2} \le 1 \qquad \forall (i, j, t) \in Excl$$

$$\forall t_1 \mid t_1 \le t \le t_1 + d_{it_1} - 1$$

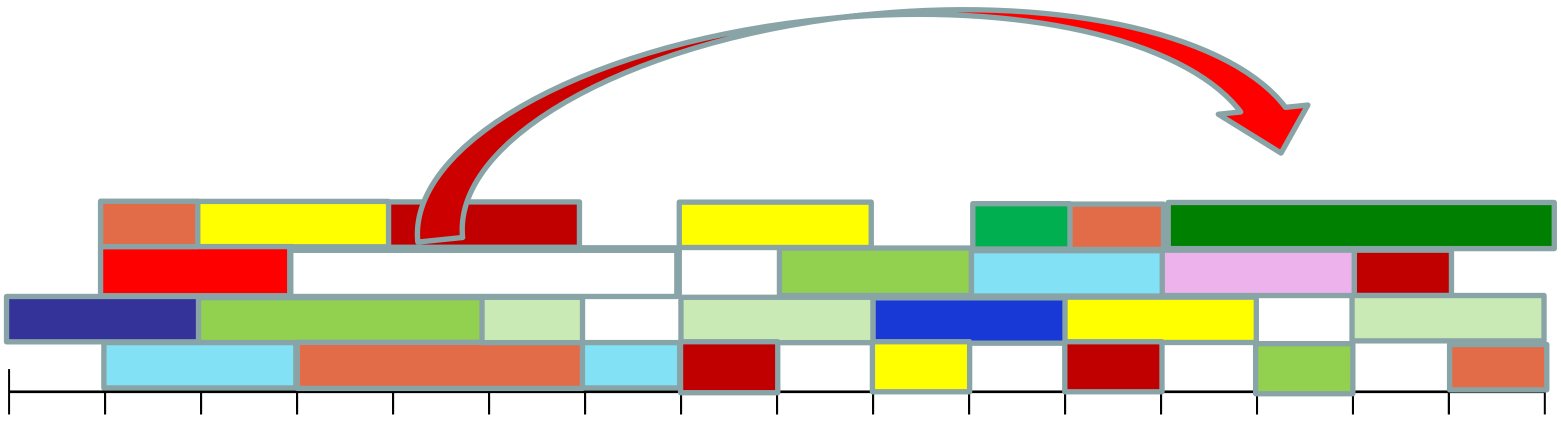
$$\forall t_2 \mid t_2 \le t \le t_2 + d_{it_2} - 1$$

$$\sum_i \sum_{\tau | \tau \le i \le \tau + d_{it} - 1} risk_{i\tau} \; x_{i\tau} \le M_t \qquad \forall t$$

How to choose the right α ?

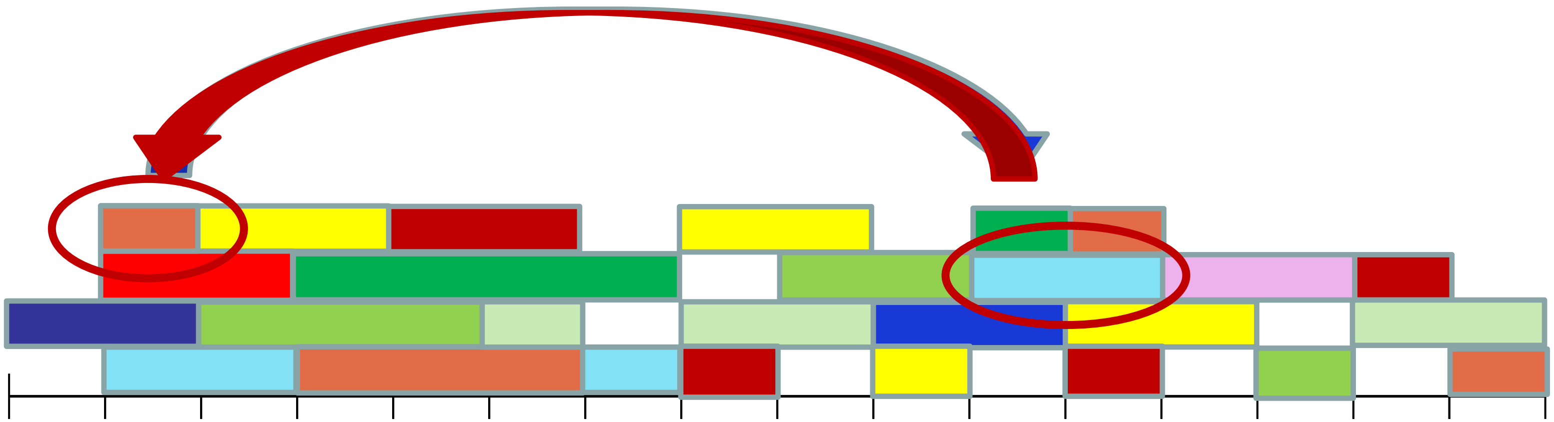
- In models 2 and 3, the best value of α is not easy to determine
- We follow an iterative procedure, covering values in the interval (0,1)
- The difficulty in obtaining feasible solutions by GRASP in the first phase is an indication of the hardness of the instance, and therefore of the number of times the model can be solved in a given time limit
- At each iteration, we solve the models with a different α, taking as initial solution the optimal solution of the previous iteration

VND: moving a single intervention

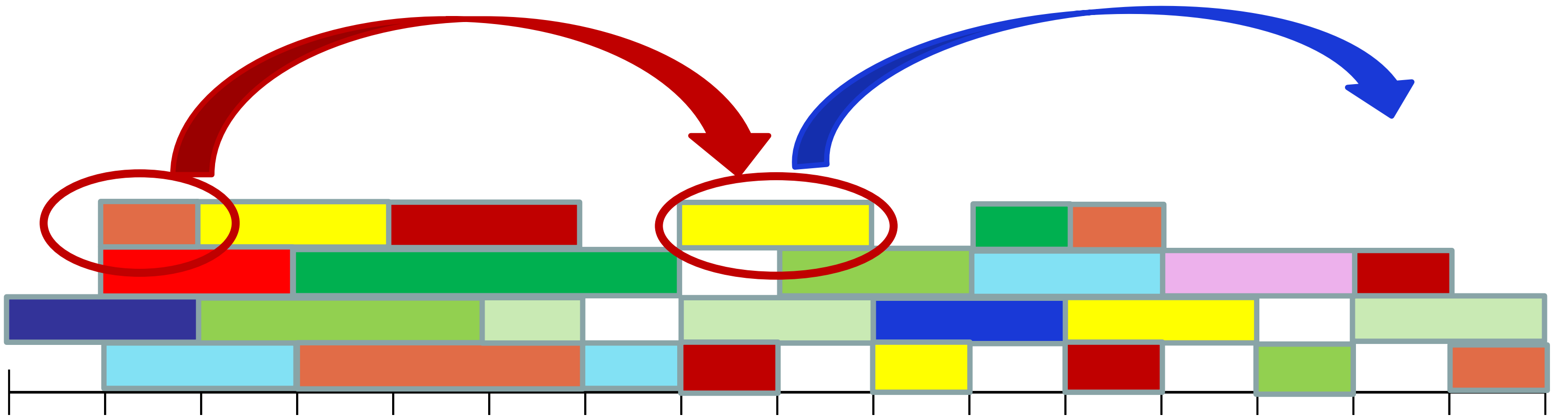


Ordered by: risk
excess

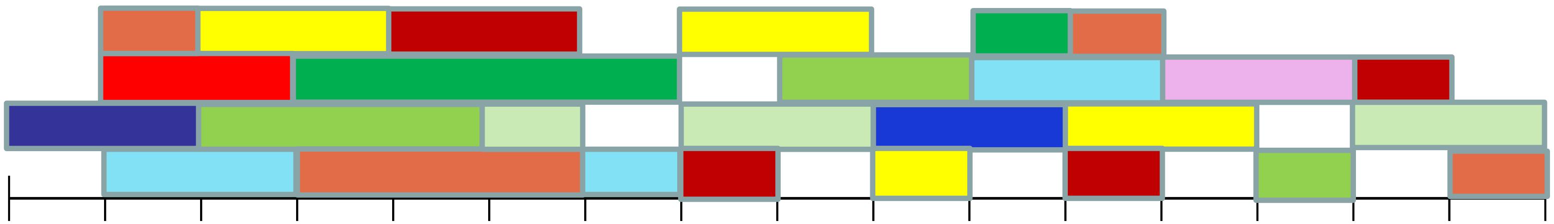
VND: exchanging pairs of interventions



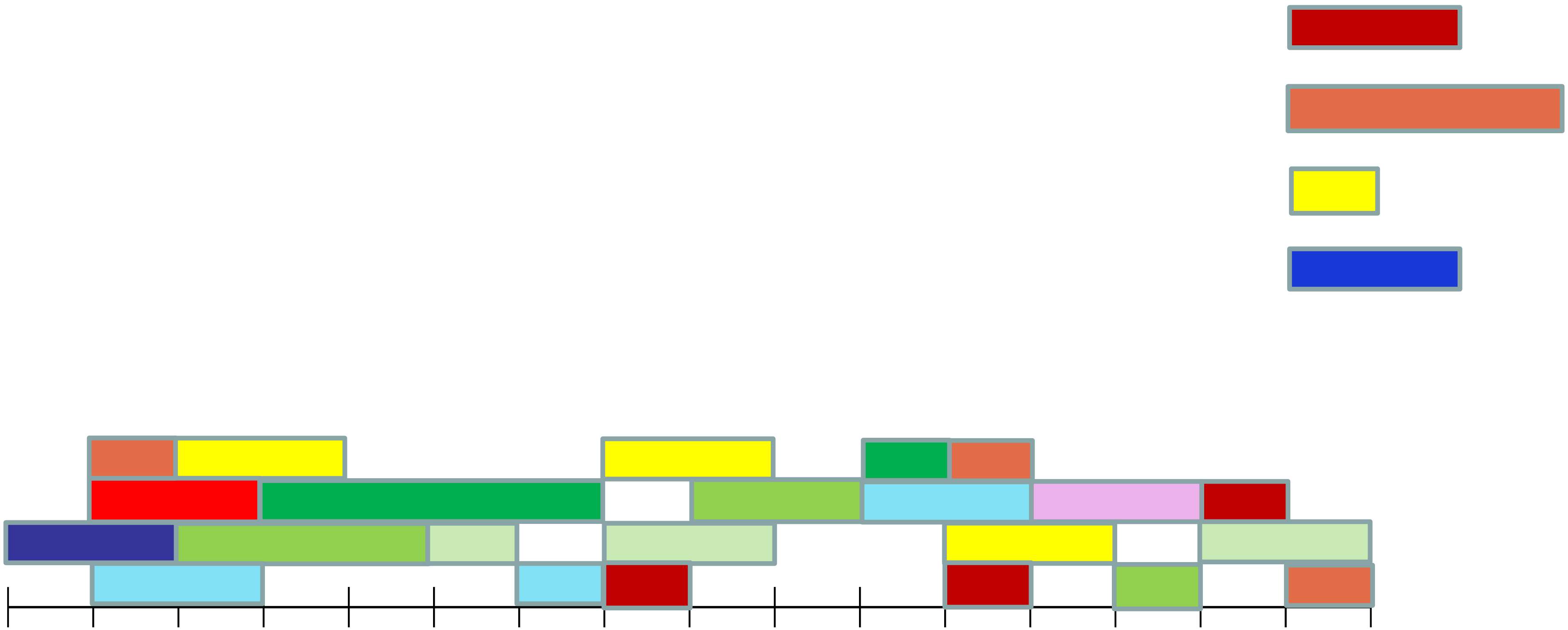
VND: simple ejection chains



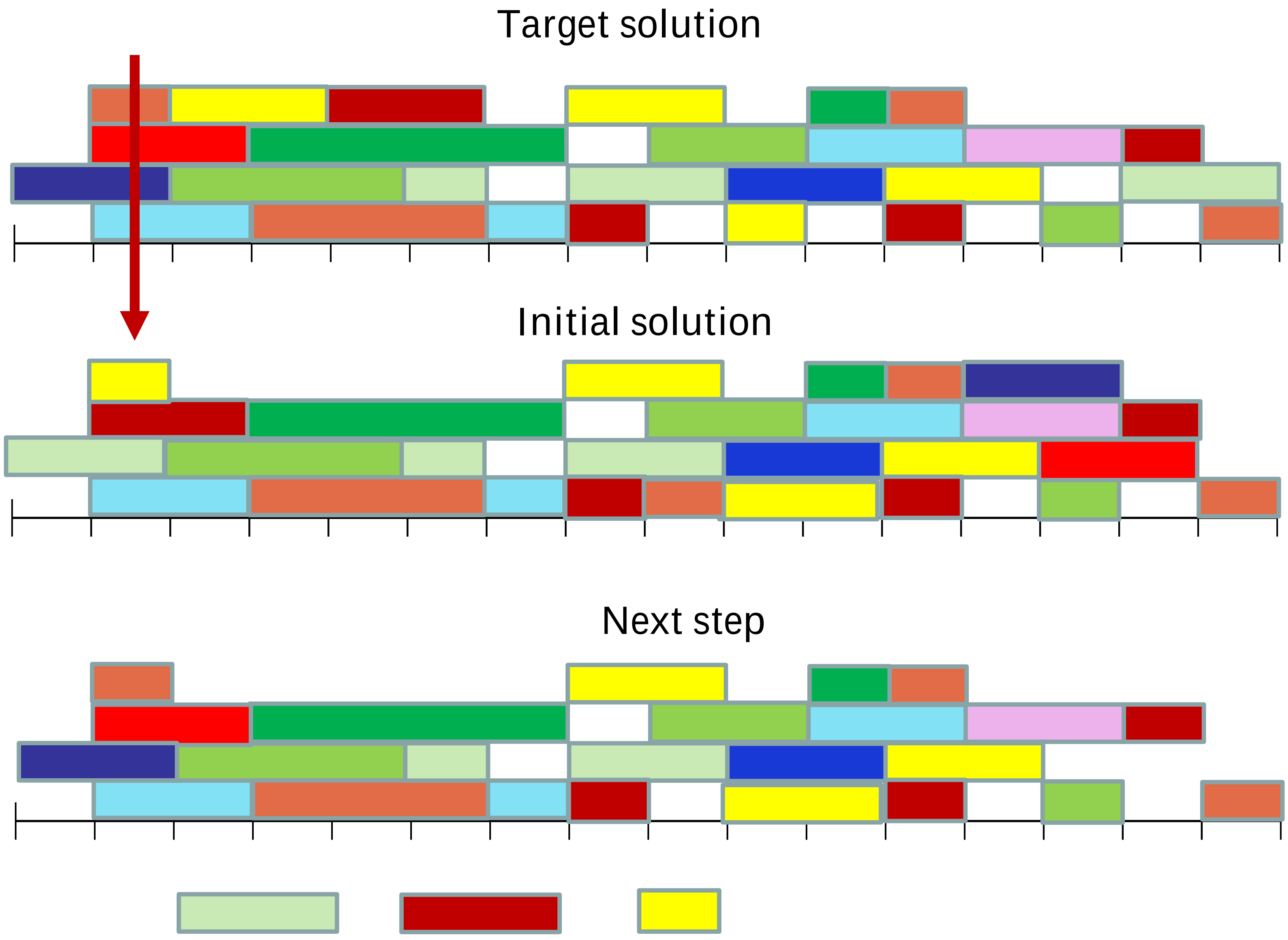
VND: Ruin & build



VND: Ruin & build



Path Relinking



RTE benchmarks

Dataset	Inst.	Periods	Interv.	Resour.	Scen.	Excl.	Feas.	Aver.
A	15	94	141	9	7038	127	15	76622
B	15	79	319	9	9462	394	12	8
C	15	106	380	9	10381	480	10	5
X	15	147	437	9	11514	553	1	0

Comparing the integer models

Are their objective functions good approximations to the real objective?

Model 1	Model 2	Model 3	BKS
7945	25989	43730	23504

Do they provide good solutions for the real problem?

Model 1	Model 2	Model 3	BKS
25635	23591	25303	23504
	0.37%		

Comparing with the best-known solutions

	900 seconds		5400 seconds	
	Our	BKS	Our	BKS
Average	23535	23513	23516	23504
% Distance	0.073		0.042	
New best	3		3	

Conclusions

- Large and challenging problem
- Excess: non-linear objective function
- Many local minima from which it is difficult to escape
- Integer model: pool of good solutions
- Improvement: VND, Path Relinking
- Competitive solutions and some new best solutions
- The validation phase will tell the practical value of the solutions

Thank you for your attention!

Any questions?

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