GARPUR Final Conference

Development of new reliability criteria.

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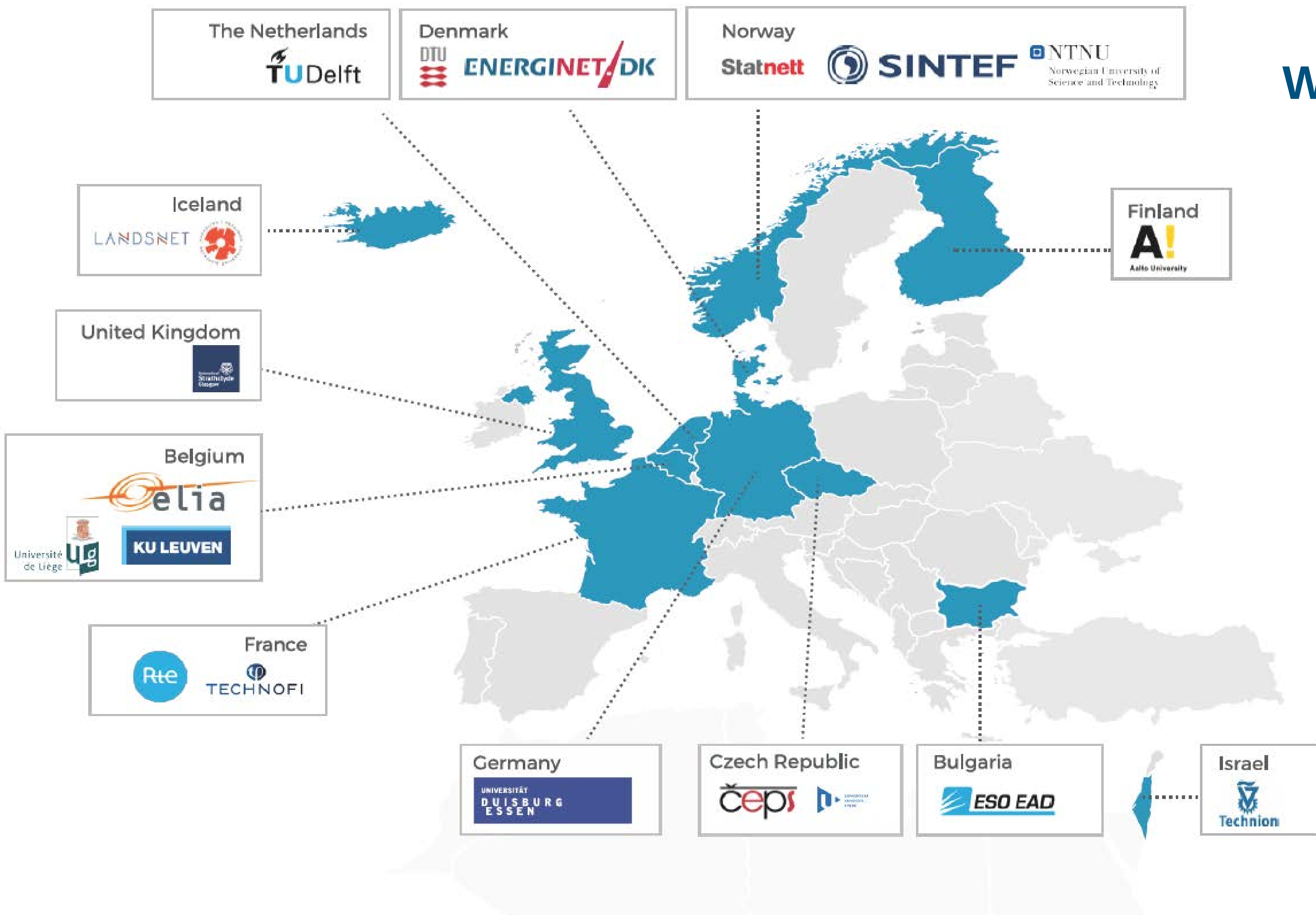
Work package on development of new reliability criteria



1 public deliverable
1 restricted deliverable
3 internal deliverables

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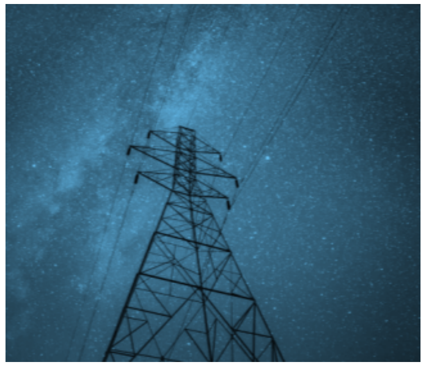
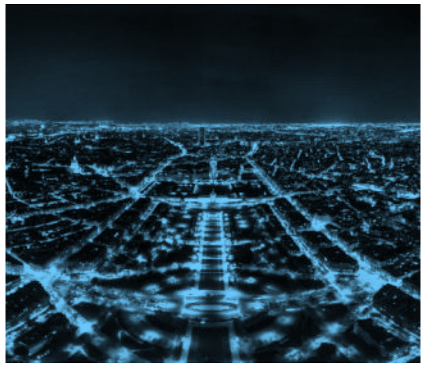
Outline of Presentation

Revisiting reliability management



The GARPUR Reliability Management Approach & Criterion (RMAC)



Proof-of-concept applications & algorithmic implementation

Conclusions

Revisiting reliability management

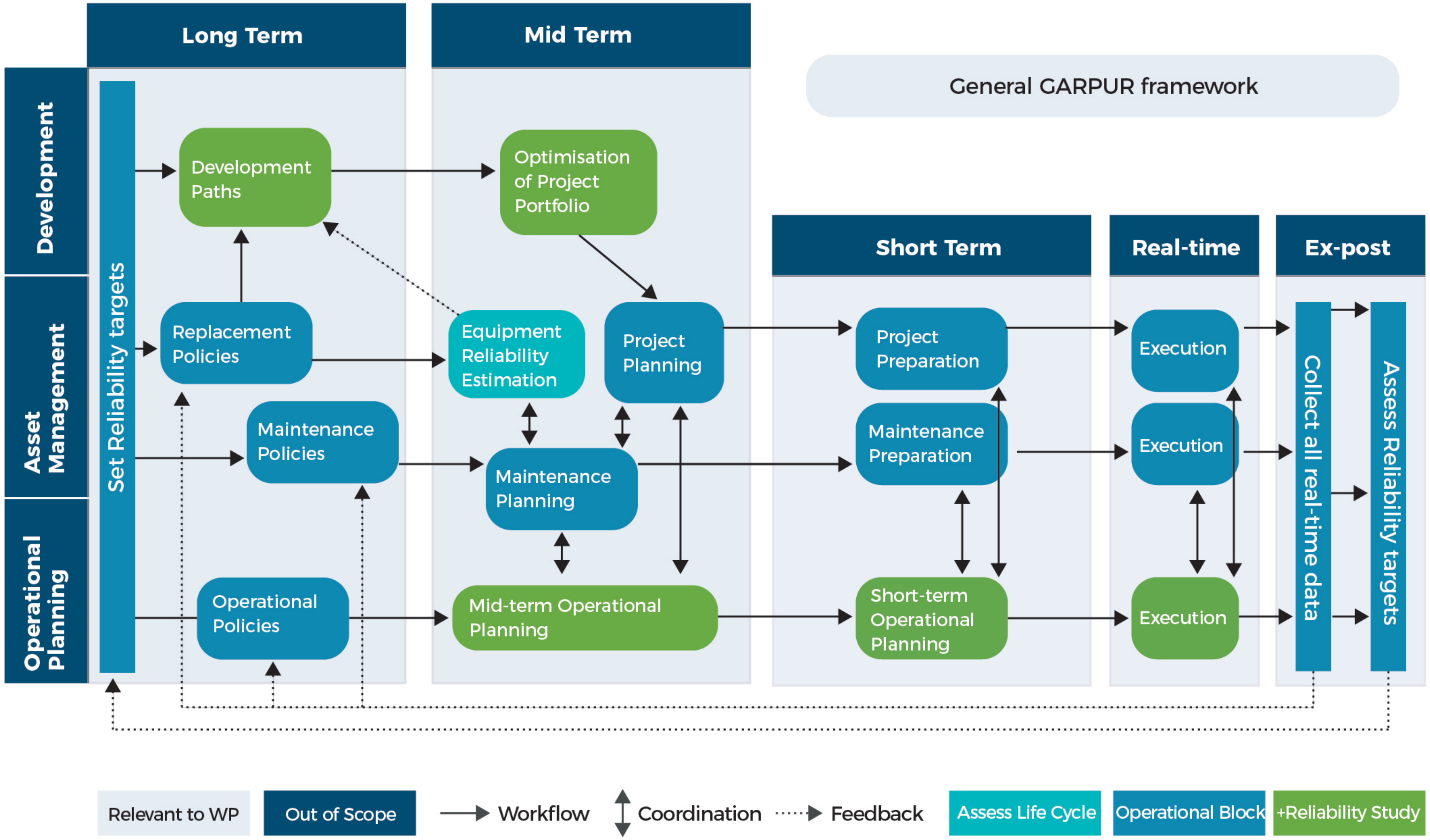
Reliability Management

*"Means taking a sequence of **decisions under uncertainty**. It aims at meeting **a reliability criterion** while minimizing the **socio-economic costs** of doing so"*

*"A **reliability criterion** is a principle imposing **the basis** to determine **whether or not** the reliability of a system is **acceptable**"*

Reliability Management

- Many different practical problems facing several uncertainties



Present use of the N-1 criterion

(e.g. in Real-Time operation)

a. **Covered next contingencies:**

- all single outages (+ possibly some common mode outages).

b. **Acceptable contingency response:**

- simulated response within steady-state (and stability) limits.

c. **Economic objective:**

- operational costs, combining TSO costs and congestion costs.

In today's evolving power system

- **N-1** should still work quite well **under "average" conditions**.

- "Average" conditions **tend to disappear**…
  - **N-1 is over-conservative**, while limiting the integration of cheap renewables?
  - **N-1 is under-conservative**, while facing adverse weather phenomena, etc?
  - **N-1 is risk-averse**, while avoiding even very minor & tolerable consequences?
  - **N-1 is risk-taking**, while neglecting the possible failure of corrective controls?

How to move forward?

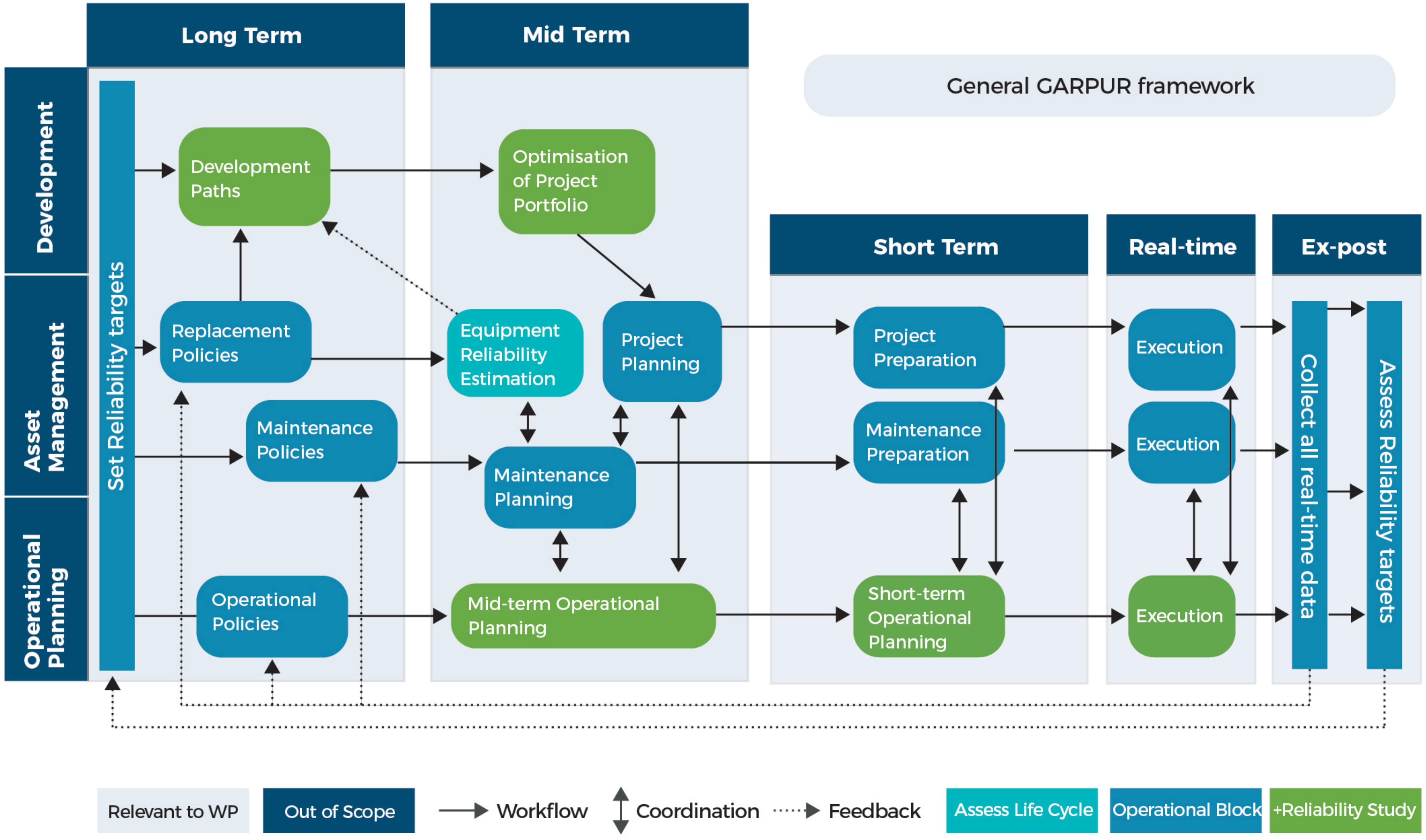
- Maintain the **solid “first principles”** from the N-1 approach.

- Dynamically adapt to more information on …
  - the spatio-temporal variability **in threat probabilities**;
  - the **socio-economic impact** of service interruptions;
  - **corrective control options** & their possible failure.

The GARPUR Reliability Management Approach & Criterion (RMAC)

Reliability Management

- Many instances of multi-stage decision making under uncertainty
- Many different practical problems facing several uncertainties



A common model for reliability management

- **Look-ahead horizon**: the period over which decision making is effective ($t \in [1, T]$).
- **Uncertainties**: modelled as exogenous processes & sequentially resolved ($\xi_{\{1,\dots,T\}} \in S$).

- **TSO decisions**:
  - firm in the 1st stage (u_0);
  - recourse is adaptive to uncertainty realizations ($u_{\{1,\dots,T-1\}}$).

- **State transition function**: describing relationship between successive states, decisions & uncertainty realizations $x_{t+1} = f(x_t, u_t, \xi_{t+1})$.

For example …

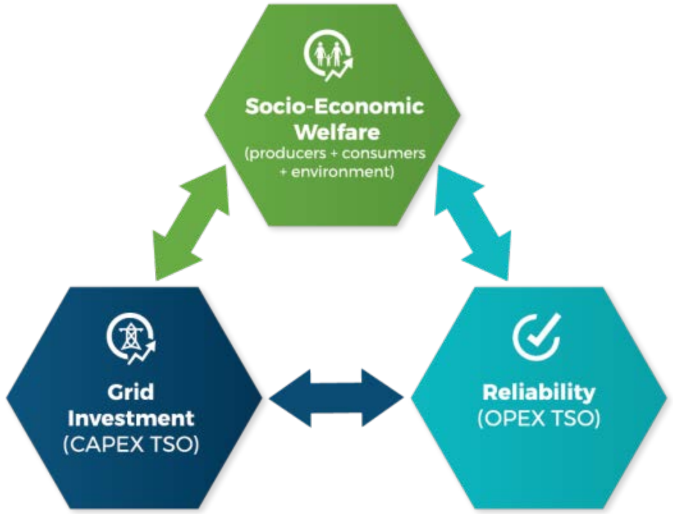
- **Real-time operation (0’-30’):**
  - First-stage decision: preventive (pre-contingency) control.
  - Uncertainty: contingency occurrence & post-contingency control behavior.
  - Recourse decisions: corrective (post-contingency) control.

- **Day-ahead operation planning (12h-36h):**
  - First-stage decision: reserve provision, must-runs…
  - Uncertainty: wind/solar power injections, load demand, weather, etc..
  - Recourse decisions: real-time operation over the next day.

- **Asset management/System development …**

The GARPUR RMAC components

Reliability target



Socio-economic objective

Discarding principle

Relaxation principle

Temporal coherence proxies

The Reliability target (1/2)

- Modeling the notion of **acceptable system performance** as a (context-specific) set of constraints $\mathbf{X}_{\alpha}$,

  ✓ **trajectory** (i.e., state evolution) acceptable if $(x_1, \dots, x_T) \in X_a$

- e.g., in **real-time** operation: no **uncontrolled cascades** (loss of stability & too large/long/widespread) **service interruptions**;

- e.g., in **day-ahead** planning: no **infeasible real-time operation**.

The Reliability target (2/2)

- Adopting a **tolerance level** ($\boldsymbol{\varepsilon}$) on the probability of realizing unacceptable system performance,

$$\mathbb{P}\left\{(\boldsymbol{x}_1, \ldots, \boldsymbol{x}_T) \in \boldsymbol{X}_a \middle| \boldsymbol{\xi}_{\{1,..,T\}} \boldsymbol{\epsilon}\, \boldsymbol{S}\right\} \geq \mathbf{1} - \boldsymbol{\varepsilon}$$

- e.g., in **real-time** operation **ensures the probability of avoiding uncontrolled cascades** (loss of stability & too large/long service interruptions);

- e.g., in **day-ahead** planning **ensures the probability of avoiding infeasible real-time** operation.

The Socio-economic objective (1/2)

- A compound cost function to be **minimized**, blending:
  - the **firm costs** associated to 1st stage decisions $(C_0(x_0, u_0))$;
  - the **expected cost of recourse** decisions $(C_t(x_t, u_t))$;
  - a terminal cost , monetizing the impact of **service interruptions** $(C_T(x_T))$.

- e.g., in **real-time** operation, costs of **preventive** actions (1st stage) and **expected** costs of post-contingency **corrective** (recourse), along with service interruption **criticality**;

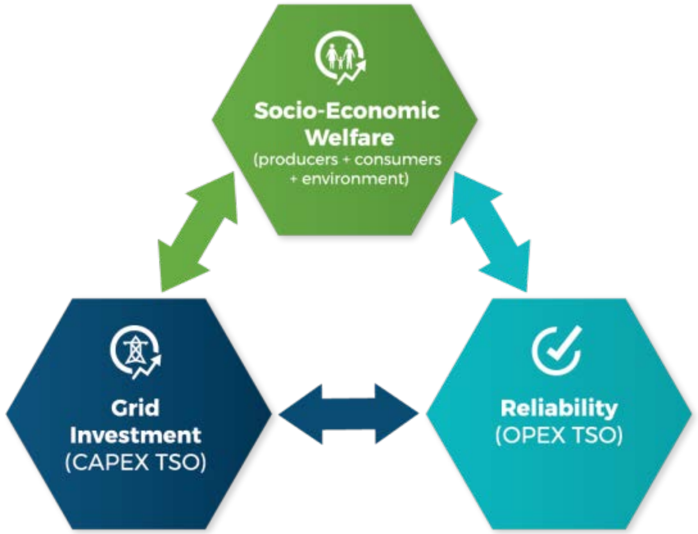
- e.g., in **day-ahead** planning, costs of **day-ahead decisions** (1st stage) and **expected** costs of **real-time** (preventive/corrective+criticality) operation (recourse).

The Socio-economic objective (2/2)

- A compound cost function to be **minimized**,

Aggregate Risk

$$C_0(x_0,u_0) + \mathbb{E}_{\xi_{1,\ldots,T}\in S}\left\{\sum_{t=1}^{T-1} C_t(x_t,u_t) + C_T(x_T)\right\}$$



- e.g., in **real-time** operation, risk equals **expected corrective control costs & service interruption costs** induced by contingencies, corrective control failures;

- e.g., in **day-ahead** planning, risk equals **expected real-time costs** (pre- and post- contingency controls, service interruption) induced by uncertainties on wind power injection/load forecast errors, etc..

The Discarding principle (1/2)

- In practice the uncertainty space is **XXXL**,

- we propose to **only neglect** those uncertainty realizations whose joint **risk falls below a discarding threshold** (ΔE), expressed in euros**.**

- e.g., in real-time operation, dynamically adapt the contingency list vs the probability x service interruption impact of credible contingencies.

- e.g., in day-ahead planning, select & prepare for scenarios (for instance, wind forecast errors) as per probability x real-time cost of operation.

The Discarding principle (2/2)

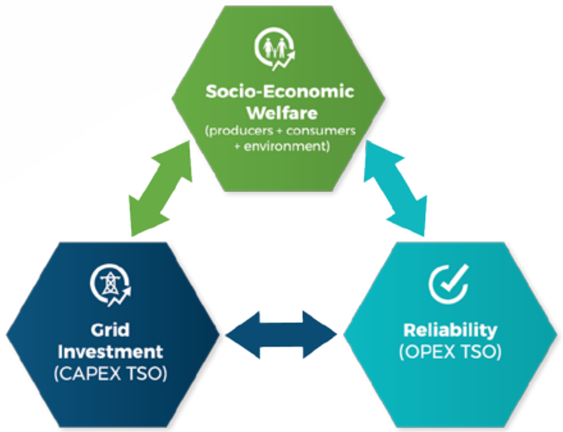
- Discard uncertainty realizations $S \backslash S_c$:

$$\mathbb{E}_{\xi_{1,\dots,T} \notin S_c} \left\{ \sum_{t=1}^{T-1} C_t(x_{t,} u_t) + C_T(x_T) \right\} \leq \Delta E$$

- e.g., in real-time operation, dynamically adapt the contingency list vs the probability x service interruption impact of credible contingencies.

- e.g., in day-ahead planning, select & prepare for scenarios (for instance, wind forecast errors) as per probability x real-time cost of operation.

RMAC Socio-economic objective



$$C_0(x_0,u_0) + \mathbb{E}_{\xi_{1,\dots,T}\in S_c}\left\{\sum_{t=1}^{T-1} C_t(x_t,u_t) + C_T(x_T)\right\}$$

cost functions $(C_{\{0,t,T\}})$
+ state transitions $x_{t+1} = f(x_t, u_t, \xi_{t+1})$

RMAC Reliability target

$$\mathbb{P}\{(x_1,\dots,x_T) \in X_a \,|\, \xi_{\{1,\dots,T\}} \in S_c\} \geq 1-\varepsilon$$

acceptability constraints (X_a)
+ tolerance level (ε)

RMAC Discarding principle

$$\mathbb{E}_{\xi_{1,\dots,T}\notin S_c}\left\{\sum_{t=1}^{T-1} C_t(x_t,u_t) + C_T(x_T)\right\} \leq \Delta E$$

discarding threshold (ΔE)

Relaxation principle

- In practice, it remains possible to arrive at a situation when **no available decision** leads to complying with both the reliability target & discarding principle!

- We propose, in any such case, to **progressively increase (relax) the discarding threshold** parameter, until the reliability target can be met;
- in other words to accept **as less additional risk** as necessary.

Temporal coherence proxies

- **What’s a proxy?**
  - A **simplified model** of a decision making context (e.g., real-time operation);

- **Where would it be used?**
  - in the **socio-economic objective** of an outer context (e.g., day-ahead operational planning) to evaluate a recourse cost component (e.g., real-time operation);
  - in the **acceptability constraints** of an outer context, seeking the feasibility of the inner decision making policy.

The GARPUR RMAC

- **A unified approach** across all time horizons & decision making contexts.

- **Fundamental components** developed in the common model of reliability management as a **multi-stage stochastic programming problem**;

- and **declined to any problem instance**, from long-term & system development, through mid-term & asset management to short-term planning & operation.

Proof-of-concept applications & algorithmic implementation

Overview

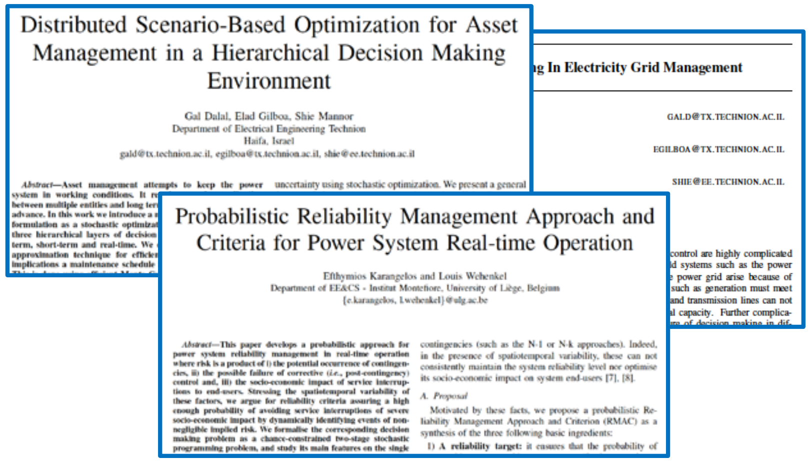
- Development of **prototype assessment & optimization algorithms** as per the principles of the GARPUR RMAC.

- Investigation of algorithmic **feasibility, scalability** vs academic benchmarks etc..

- **Demonstrative findings** on the outcomes of the RMAC with respect to the “classical” N-1 assessment & decision making approach.

- Major achievements published in **8 conference papers** (+ a pending journal publication).

```

for idx in 1:size(Clog1s,1)
  print(contfile,round(Clog1s[idx,:],0),"\n")
end

for s in 2:Sset

  PdRt[:,1,s]=Pdem[:]+dPD[:,s].*Pdem[:]
  PdRt[:,2,s]=voll
  PwRt[:,s]=WP[:,s]
  if size(LinAv1S,2) <= CardMax

    LinAvScen[:,1:size(LinAv1S,2),s]=LinAv1S
    CmatScen[1:size(LinAv1S,2),:,s]=Cmat1S

  else
```


Distributed Scenario-Based Optimization for Asset Management in a Hierarchical Decision Making Environment

Gal Dalal, Elad Gilboa, Shie Mannor

Probabilistic Reliability Management Approach and Criteria for Power System Real-time Operation

Efthymios Karangelos and Louis Wehenkel

Summary of applications

- **Real-time operation (Rt-RMAC)**:
  - risk assessment & security constrained optimal power flow (SCOPF).

- **Short-term operational planning (St-RMAC)**:
  - risk assessment & security constrained optimal power flow (SCOPF);
  - machine learning of proxies for reliability management.

- **Mid-term & asset management (Mt-RMAC)**:
  - simulation based stochastic optimization for outage scheduling.

Real-time RMAC (Rt-RMAC) prototypes

- vs uncertainty on **contingencies & corrective control failures**

Discarding problem

How to select a manageable **contingency subset** as per the **RMAC discarding principle**?

Contingency

Subset

Optimal

Decisions

Control problem

Choose **preventive** and/or **corrective control** as per the **RMAC reliability target** & **socioeconomic objective**.

Rt-RMAC: algorithmic implementations

- **Discarding problem**:
  - upgraded cascade simulation algorithms originally proposed in the literature to estimate **per contingency interruption costs**;

- **Control problem**:
  - Security Constrained Optimal Power flow (SCOPF) formulations:

    a. DC-approximation, **mixed integer linear** problem (MILP);

    b. full AC- model, **mixed integer non-linear** problem (MINLP).

  - Upgraded **iterative contingency clustering** scheme to focus on MINLP reliability target achievability.

Rt-SCOPF exemplary result

- **Reliability target** functionality

Tolerance level (ε)	0	10^{-6}	10^{-5}	10^{-4}
Preventively Secured Contingencies	42	41	40	36
Correctively Secured Contingencies	0	1	1	4
Not Secured Contingencies	0	0	1	2
Total	42	42	42	42

- **(ε=0)**: blocks corrective control due to its possible failure,
- **(ε>>):** fewer low probability contingencies “covered by preventive/corrective controls.

Rt Security Constrained OPF

- Deterministic State-of-the-art

$$\min_{\mathbf{u}} CP(x_0, u_0)$$

- GARPUR RMAC approximation

$$\min_{\mathbf{u,z,y}} \left\{ C_0(x_0, u_0) + \sum_{c \in \mathcal{C}_c} \pi_c \cdot CC(x_c, u_c) + \sum_{c \in \mathcal{C}_c} \pi_c \cdot \pi_x(c) \cdot CR^{\max} \right\}$$

$$\sum_{c \in \mathcal{C}_c} \pi_c \cdot \pi_x(c) \leq \epsilon_{RT}$$ **reliability target**

	Deterministic State-of-the-art		GARPUR RMAC approximation	
preventive	$g_0(x_0, u_0) = 0$		$g_0(x_0, u_0) = 0$	
	$h_0(x_0, u_0) \leq \mathcal{L}$		$h_0(x_0, u_0) \leq \mathcal{L}$	
intermediate post-contingency	$g_c^s(x_c, u_0) = 0$	$\forall c \in \mathcal{C}_c$	$g_c^s(x_c, u_0, z_c) = 0$	$\forall c \in \mathcal{C}_c$
	$h_c^s(x_c, u_0) \leq \mathcal{L}^s$	$\forall c \in \mathcal{C}_c$	$h_c^s(x_c, u_0, z_c) \leq \mathcal{L}^s$	$\forall c \in \mathcal{C}_c$
corrective post-contingency	$g_c(x_c^{b_1}, u_c) = 0$	$\forall c \in \mathcal{C}_c$	$g_c(x_c^{b_1}, u_c, z_c) = 0$	$\forall c \in \mathcal{C}_c$
	$h_c(x_c^{b_1}, u_c) \leq \mathcal{L}$	$\forall c \in \mathcal{C}_c$	$h_c(x_c^{b_1}, u_c, z_c) \leq \mathcal{L}$	$\forall c \in \mathcal{C}_c$
	$\lvert u_0 - u_c \rvert \leq \Delta u_c$	$\forall c \in \mathcal{C}_c$	$\lvert u_0 - u_c \rvert \leq \mathbf{y}_c \cdot \Delta u_c$	$\forall c \in \mathcal{C}_c$

continuous & discrete auxiliary variables

$$\pi_x(c) = z_c + (1 - z_c) \cdot \sum_{j \in \mathcal{J}} y_{c,j} \cdot \pi_{bf,j} \quad \forall c \in \mathcal{C}_c$$

$$z_c \in \{0;1\} \quad \forall c \in \mathcal{C}_c$$

$$y_{c,j} \in \{0;1\} \quad \forall c, j \in \mathcal{C}_c \times \mathcal{J}.$$

Proper model of most post-contingency controls is anyhow discrete!

Short-term RMAC (St-RMAC) prototype

- vs uncertainty on **weather state & renewable power injections**

Discarding problem

How to select a manageable **scenario subset** as per the **RMAC discarding principle**?

Scenario → **Subset**

Optimal ← **Decisions**

Control problem

Choose **planning decisions** as per the **RMAC reliability target** & **socioeconomic objective**.

St-RMAC: algorithmic implementation

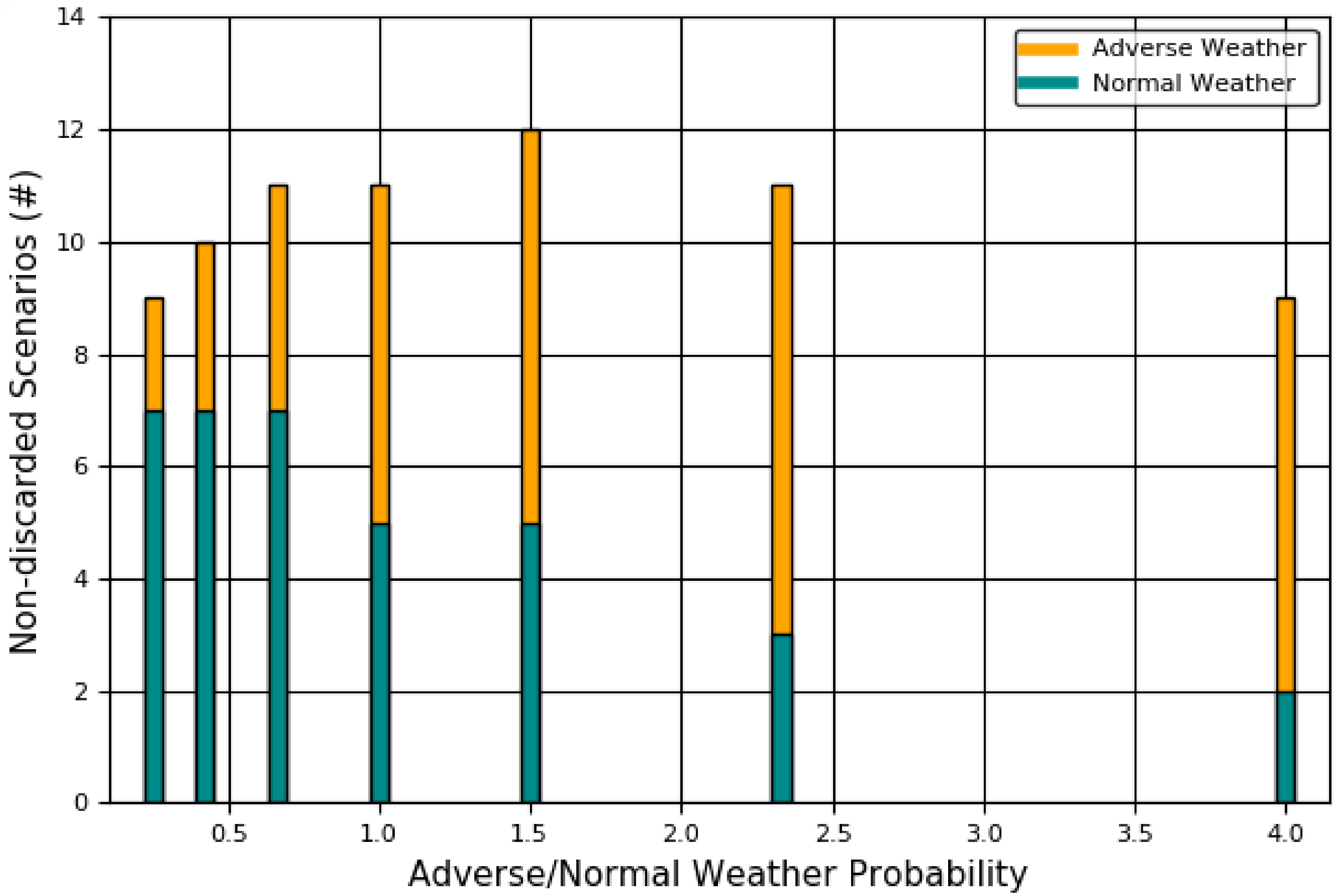
- Integrating DC-SCOPF **“proxies” of the Rt-RMAC**

- **Discarding problem**:
  - per scenario, evaluate the cost necessary to meet the Rt-RMAC;
  - or, if need be, to meet the relaxed version of the Rt-RMAC.

- **Control problem**:
  - 4-stage security Constrained Optimal Power flow (SCOPF) formulated as a mixed-integer programming problem;
  - planning decisions: generation start-up/shut-down & reserve booking.

St-RMAC exemplary result

- **Discarding principle** functionality



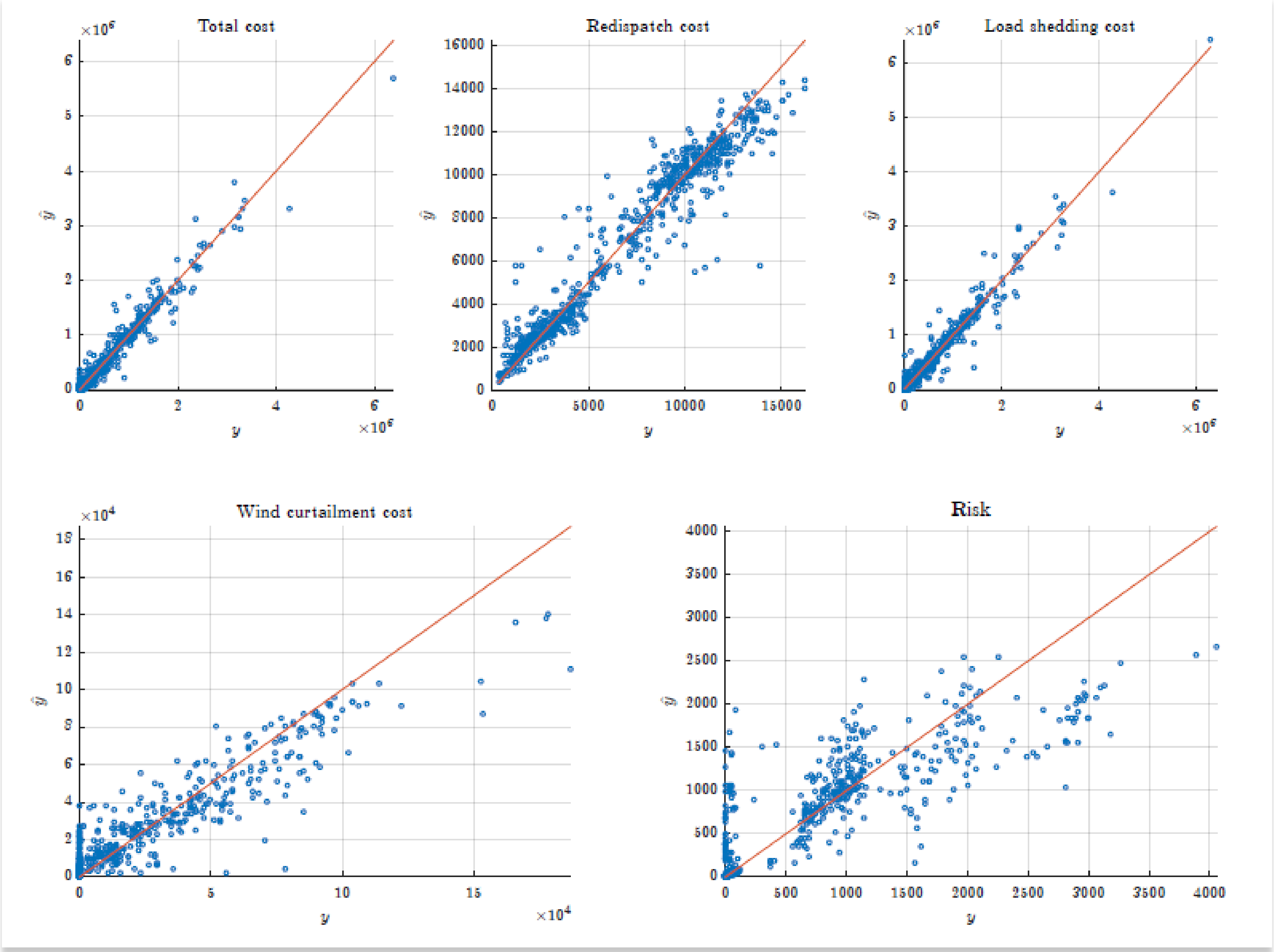
- Choice of non-discarded scenarios follows the progressive increase in the probability of realizing the adverse weather state.

Machine Learning of Proxies for the St-RMAC

- Tests on the **suitability of several learning algorithms** in order to predict :
  - real-time reliability control **costs**;
  - **risk** implied by real-time decisions;
- and, gain understanding of the real-time problem via **feature importance**.
- Database built while modeling the N-1 criterion for real-time operation.

Machine Learning of Proxies

- Exemplary result:



Conclusions

The GARPUR RMAC

- **Why?**
  - **adaptability** to the spatio-temporal variability to **threat probabilities & consequences**;
  - **exploiting the full potential** of the system (e.g., corrective control) in a rational manner.

Looking forward …

- **Reliability management** was/is/will be a multi-stage & multi-level decision making under uncertainty problem;

- **RMAC vision reachable** at the proof-of-concept level;

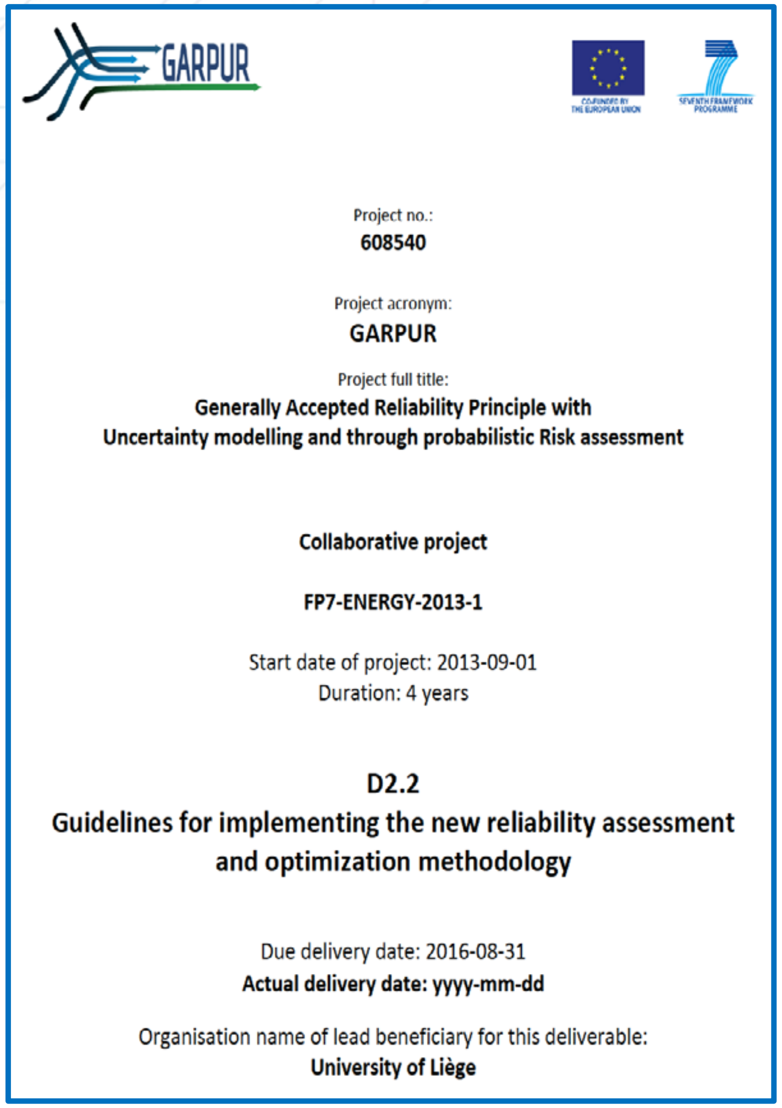
- We could certainly make the most of recent advances:

  - in **simulation tools**, to more accurately study the dynamic behavior of the system & identify most prominent risks;

  - in **optimization & constraint satisfaction** to tackle the large-scale, non-convex, mixed-integer non-linear problems;

  - in **machine learning & statistics** to generate “proxies” for the large-scale assessment & optimization problems.

To find out more…


GARPUR

Project no.:
608540

Project acronym:
GARPUR

Project full title:
Generally Accepted Reliability Principle with
Uncertainty modelling and through probabilistic Risk assessment

Collaborative project

FP7-ENERGY-2013-1

Start date of project: 2013-09-01
Duration: 4 years

D2.2
Guidelines for implementing the new reliability assessment and optimization methodology

Due delivery date: 2016-08-31
Actual delivery date: yyyy-mm-dd

Organisation name of lead beneficiary for this deliverable:
University of Liège

- Please visit www.garpur-project.eu
- **GARPUR D2.2** “Guidelines for implementing the new reliability assessment & optimization methodology”,
- **8 publications** in peer-reviewed conference proceedings.

THANK YOU FOR YOUR ATTENTION!

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