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Applying High Performance Computing to the European Resource Adequacy Assessment

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Organization

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- Context and motivation
- Problem formulation
- Proposed approach
- Results

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Context and motivation

European Resource Adequacy Assessment

The **European Resource Adequacy Assessment (ERAA)** aims at measuring the ability of the power system to react to future uncertain conditions

- The study is developed, on a yearly basis, by the **European Network of Transmission System Operators for Electricity (ENTSO-E)**

- In a nutshell, the study simulates the power network for the up-coming future (at an EU-scale) and measures **adequacy metrics**: “metrics to measure blackouts intensity”

Motivation

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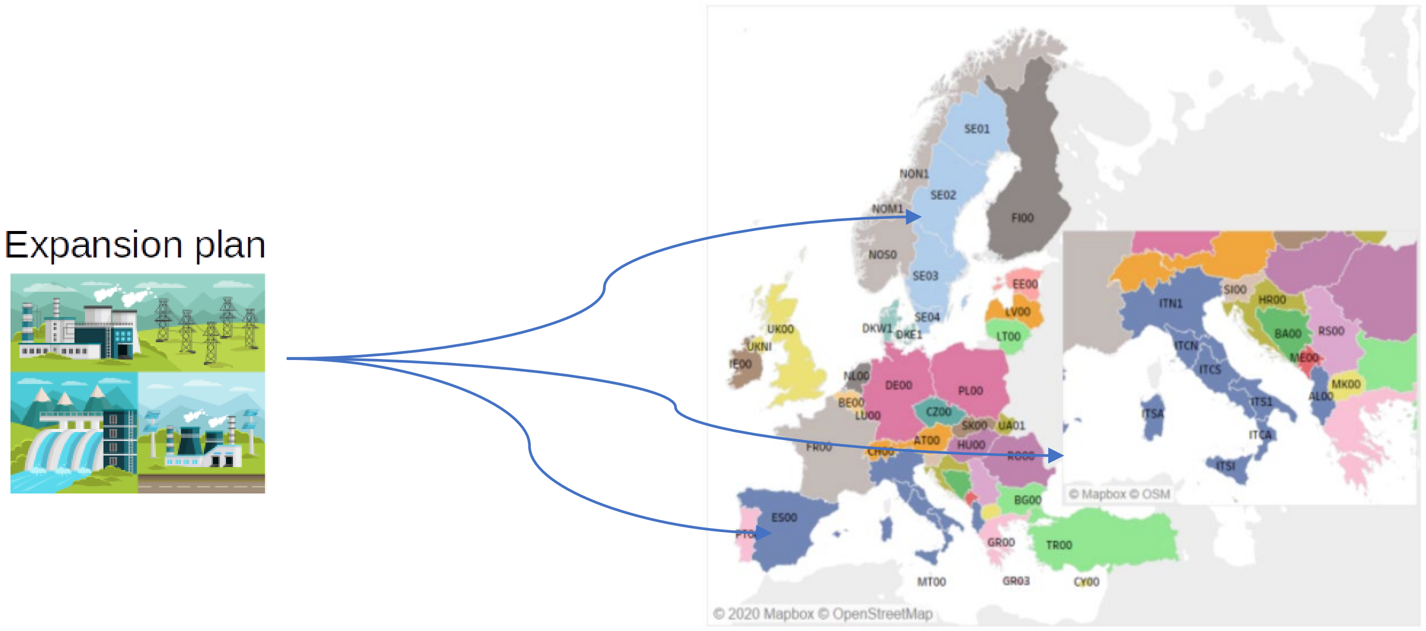
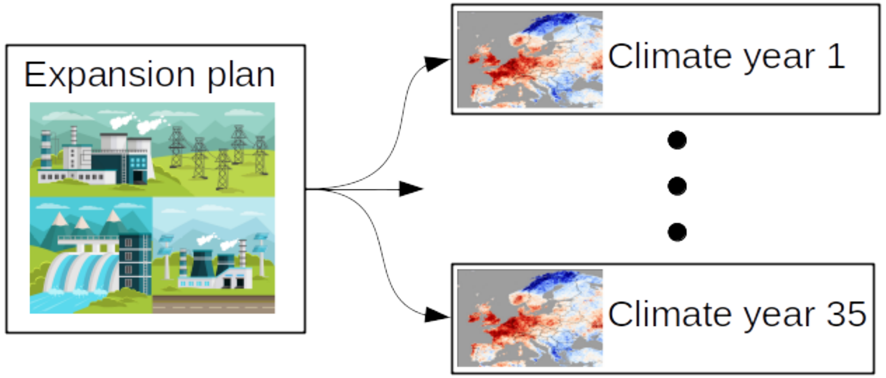
- We would like to simulate the power network for the **upcoming years**
- Therefore, we need to calculate how the **power network will look like**
- Within the ERAA this problem is called the **Economic Viability Assessment (EVA)**



Motivation (2)

- **The EVA aims at calculating an expansion plan** (expansion and retirement opportunities) of power plants for the entire European network
- However, **there is uncertainty** as we don't know the precise climatic future conditions, but we have a set of possible future conditions
- **The expansion plan must behave optimally under uncertainty**, this leads us to a stochastic optimization problem



So far, the ability to solve a **stochastic EVA has been limited**

Research

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Research

- Can we tackle the **stochastic EVA**?
- Does the stochastic nature affect the **adequacy**?

Our approach

- Use **decomposition methods** in combination with **parallel computing**

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Problem formulation

Capacity generation expansion

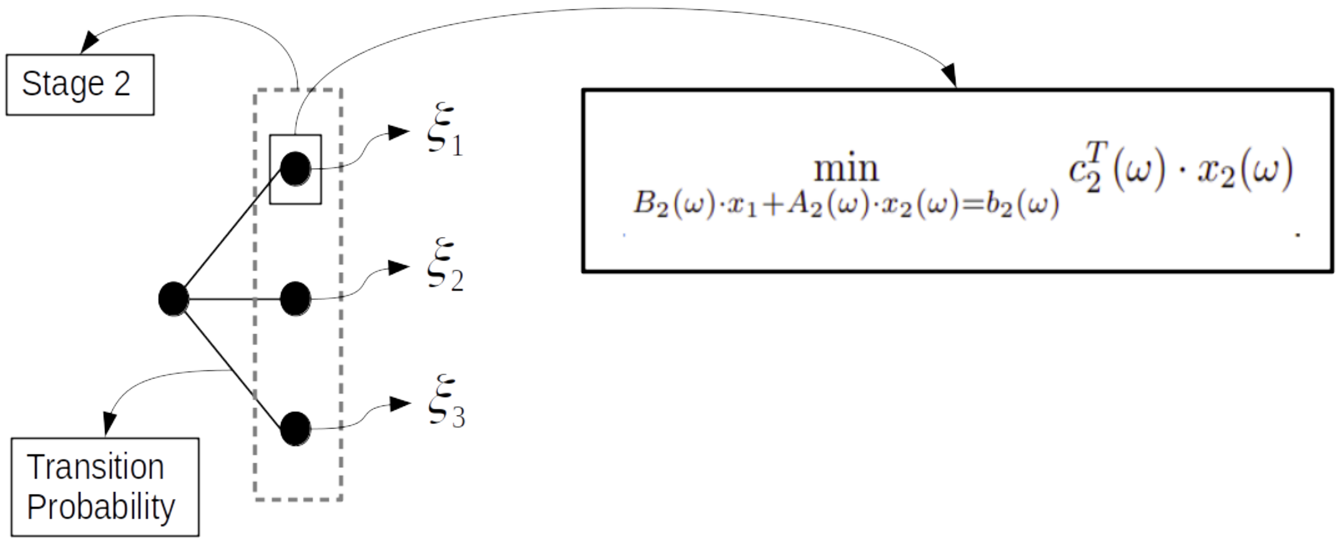
**Minimize : **investment - retirements + E[operational costs]

Subject to :

1. Expansion constraints
2. Load balance constraints
3. Technical constraints on the generators (we do not model unit commitment)
4. Transmission network constraints (not flow based, but we can handle them)
5. Batteries constraints (time-coupled)
6. Hydrological constraints (time-coupled)

Over a full year with hourly resolution (8760 time-steps)

Two stage problem formulation



- **First stage:** Minimize investment and maximize retirement opportunities
- **Second stage:** Operational problem (economic dispatch)

Modelling issues

- The **economic dispatch** problem, i.e., the second stage problem is a **large-scale LP**: model the pan-European network + there are 8760 time-steps

Note: equations 5,6 couple these 8760 time-steps

- There are **35 climatic uncertain conditions** leading to an untraceable formulation

Methods proposed in the capacity expansion literature

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State-of-the-art approaches for capacity expansion include:

- L-shaped algorithm
- Progressive hedging algorithm
- Column-constraint generation-based algorithms

Each **iteration** of these approaches is **non-trivial:** we require to solve the economic dispatch subproblems. The scale of the pan-European transmission network & the time resolution implies each one of these solves is hard

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Proposed approach

Second stage relaxation algorithm (idea)

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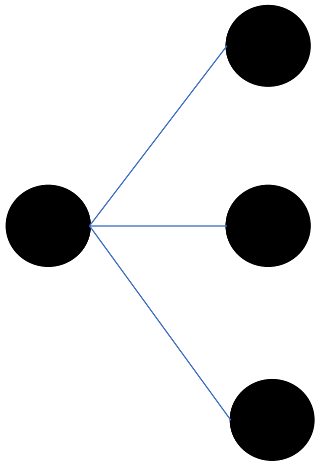
Decide expansion plan

Economic dispatch



Intuitive description

If the second stage (the economic dispatch) is easy, we know what to do (L-shaped, progressive hedging, ..)

1. Let’s consider a relaxation of the economic dispatch, the apply one of these known schemes.

2. We refine the relaxation

Key idea

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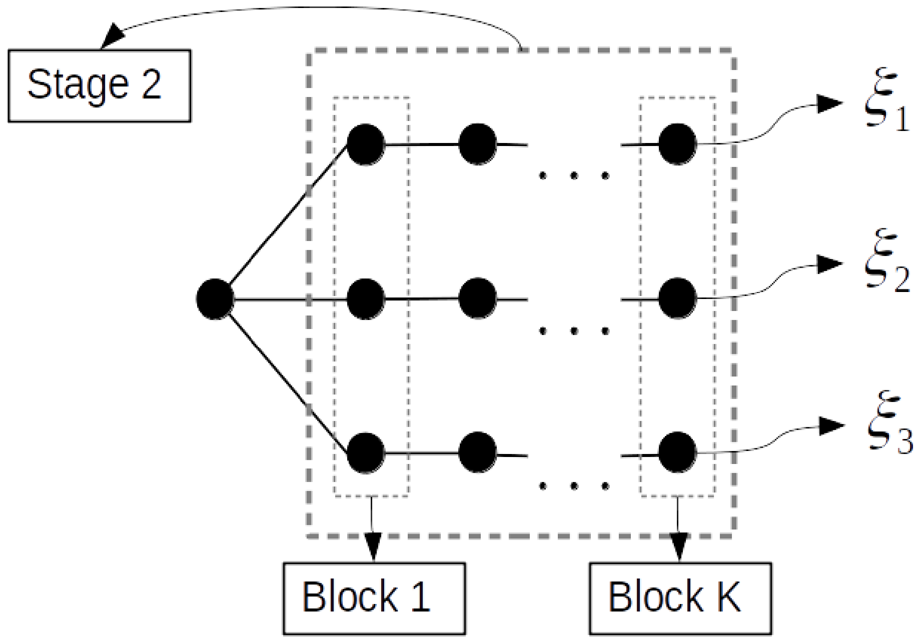
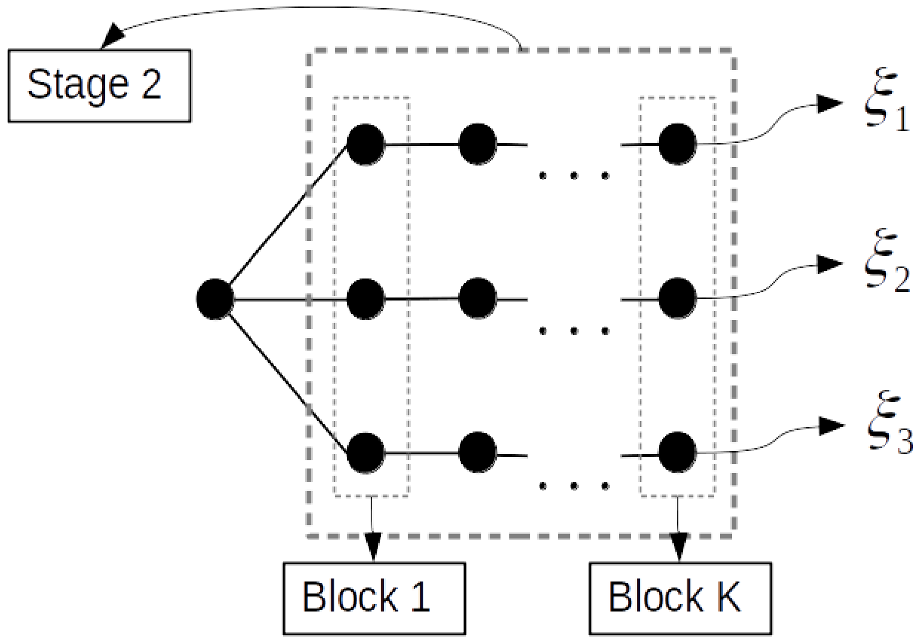
- **Economic dispatch relaxation** (based on value function decomposition)

Economic dispatch relaxation



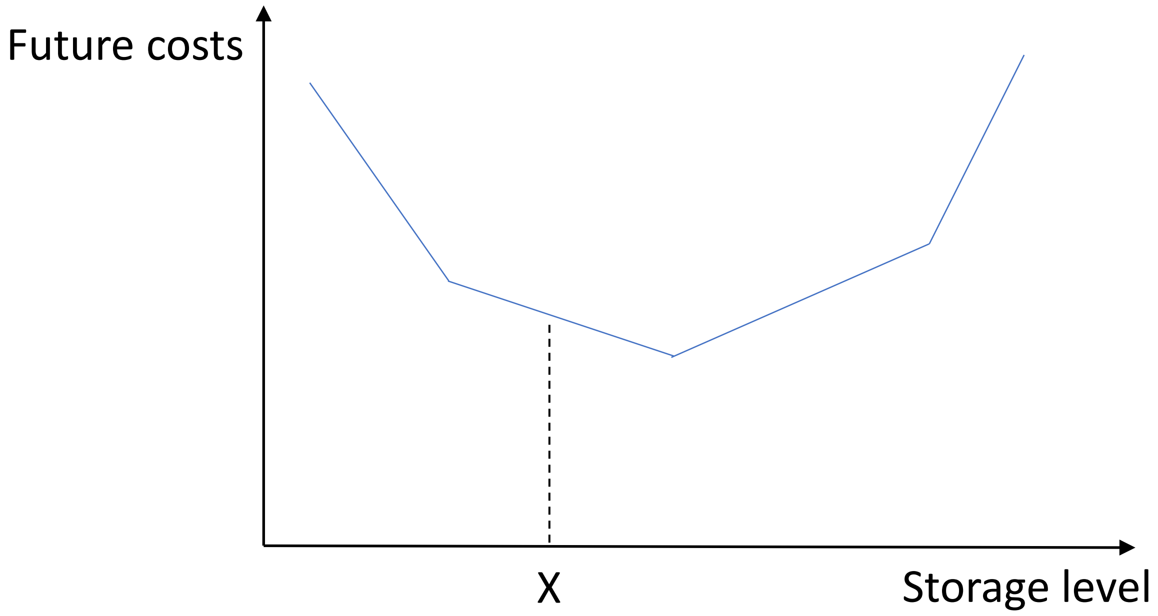
- A **chronological decomposition** of the economic dispatch
- Each block consists of a 4-day operational problem
- The **first block** is used as approximation of the economic dispatch

Economic dispatch relaxation (2)



- **Issue:** these blocks don't know what is going to happen in the future
- **Solution:** we attach a **value function Vt** to each block

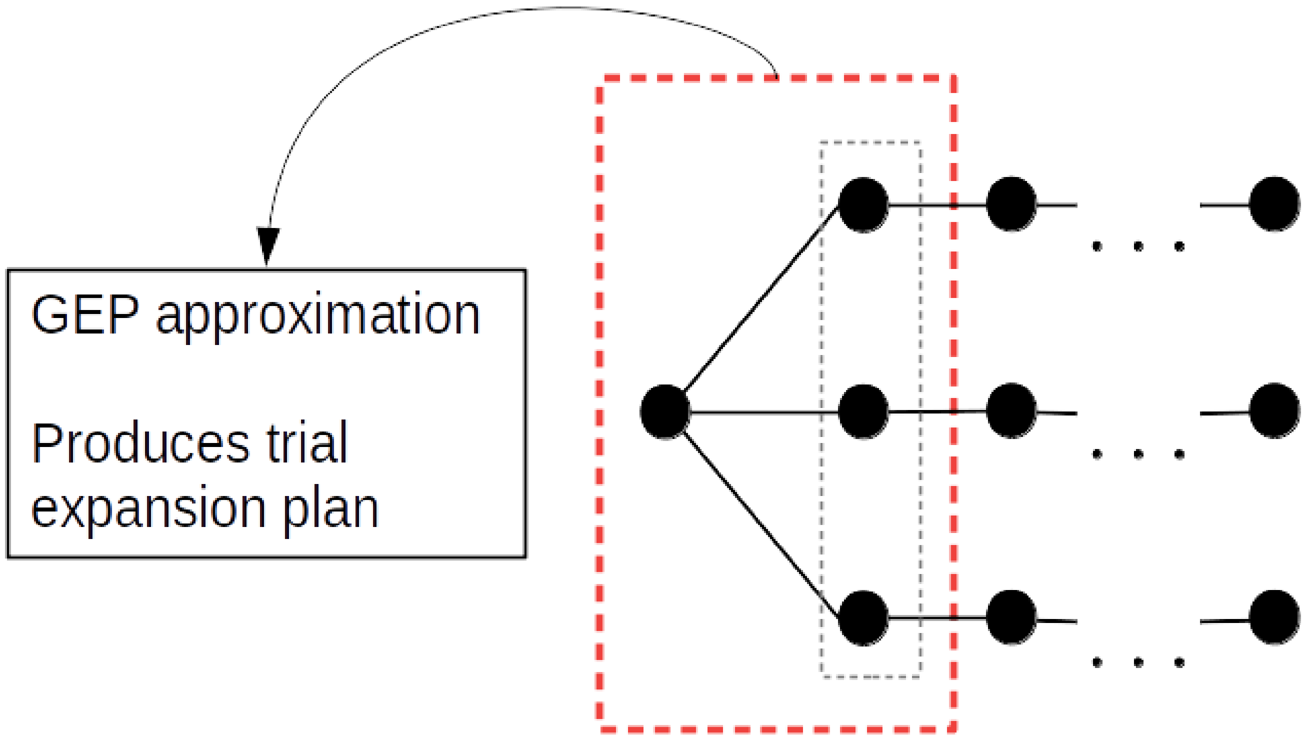
Value function



- In a nutshell: It’s a function that gives your **future costs** for having available X amount of energy (for instance in hydro reservoirs, batteries)
- The function is “nice” (convex, piece-wise linear)
- Each line is called a **cut**

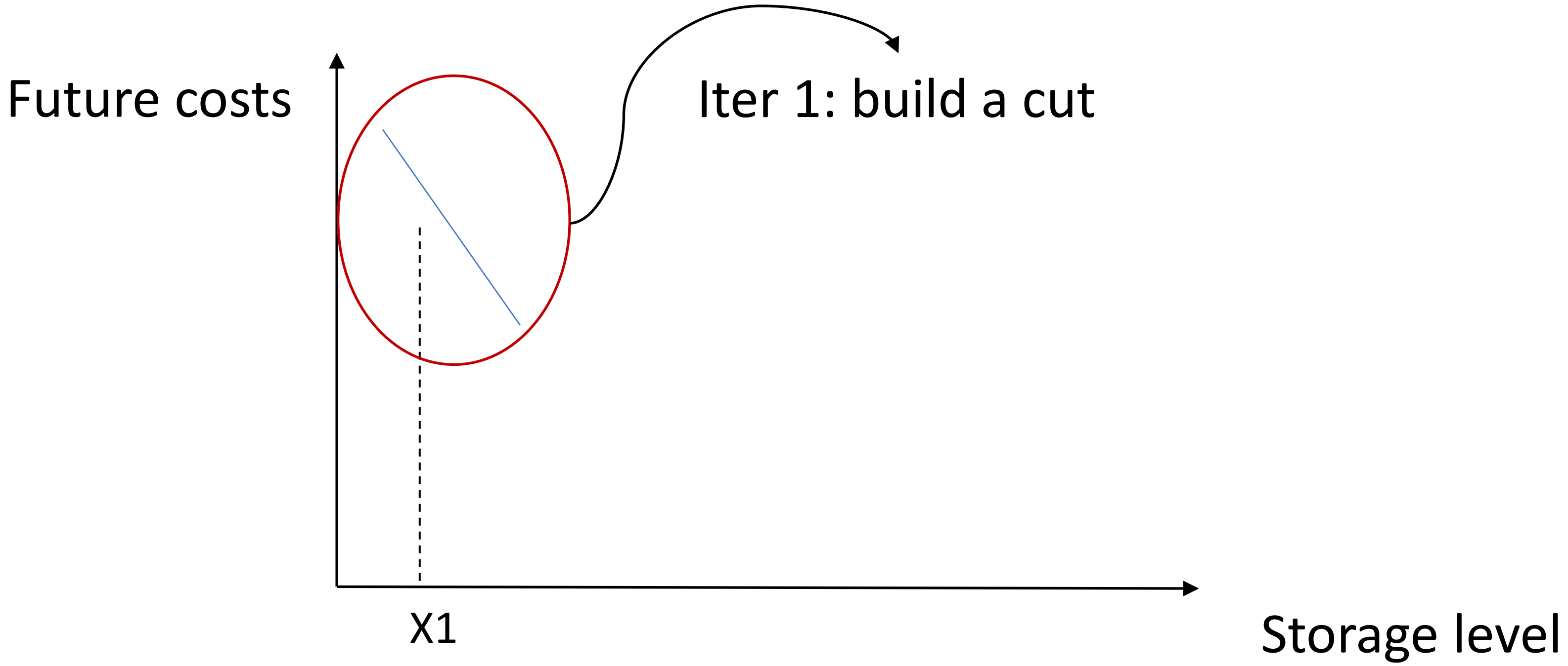
Relaxed two-stage problem

- We attach a **value function Vt** to each block
- The **economic dispatch** is approximated by the **first block subproblem**.
- The **overall problem is approximated** by:



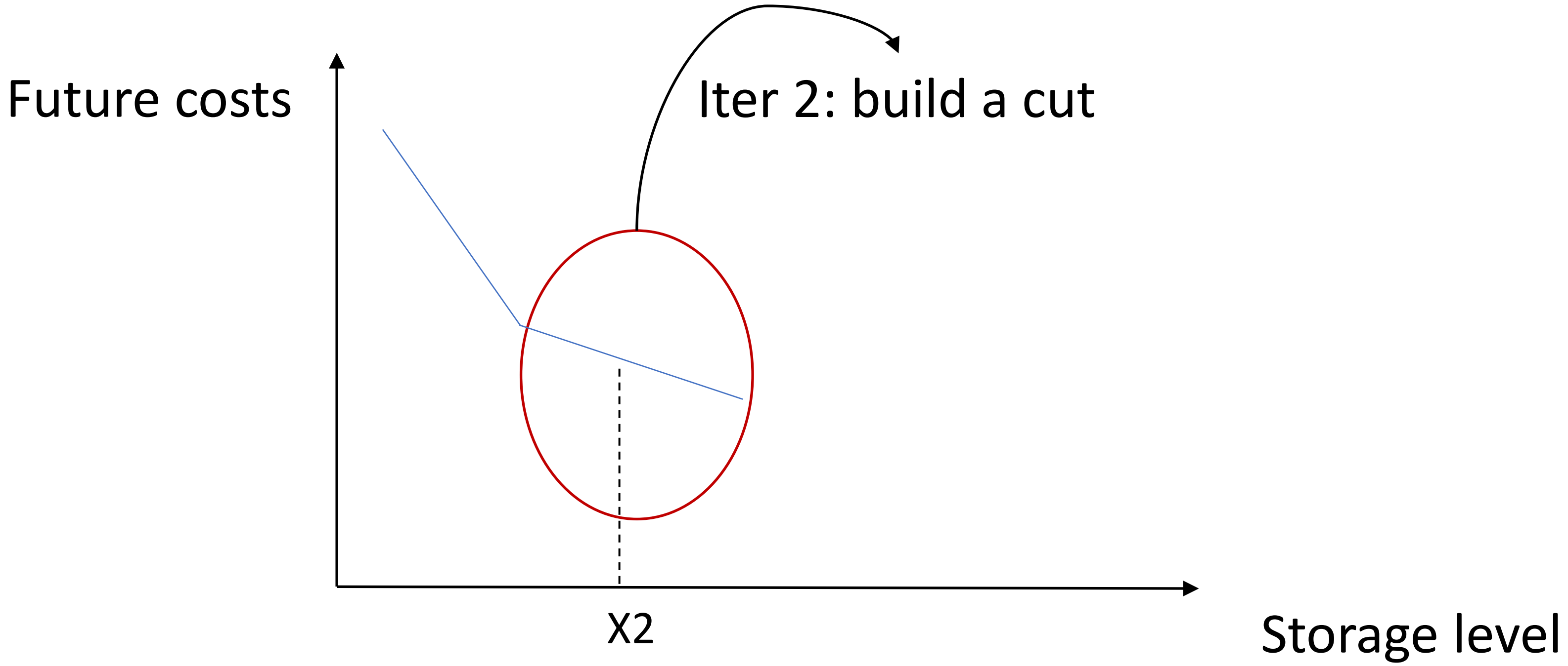
Algorithms to calculate value function approximations

Iterative schemes:



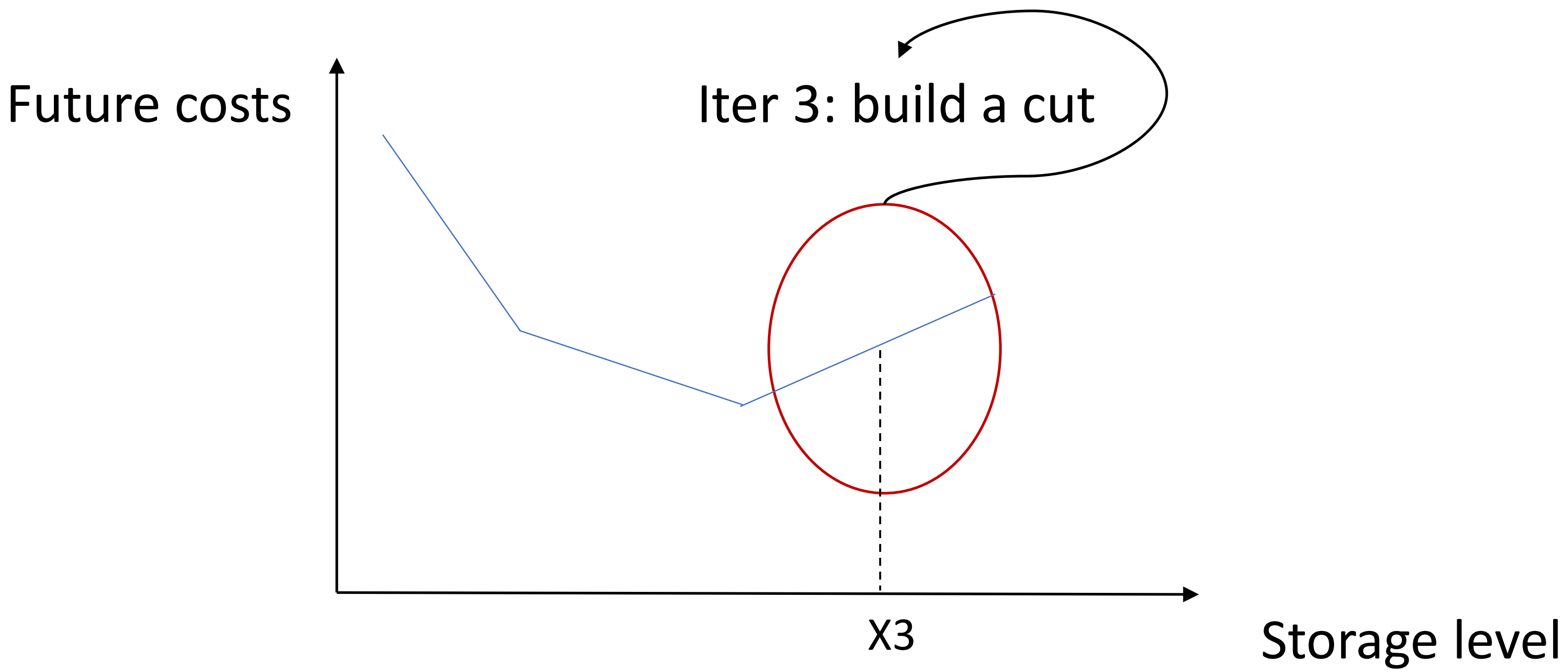
Algorithms to calculate value function approximations

Iterative schemes:



Algorithms to calculate value function approximations

Iterative schemes:



Second stage relaxation algorithm

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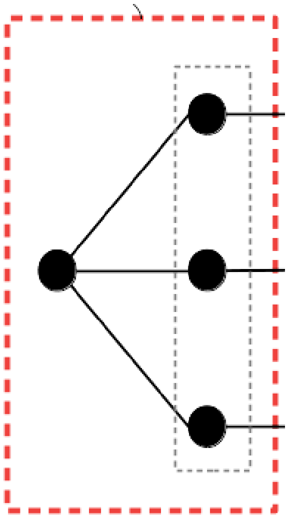
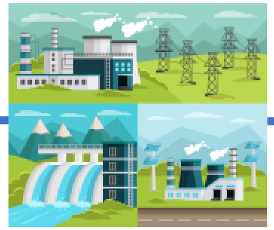
- **Iterative** two step process:

Solve the relaxed two-stage problem.



Expansion plan



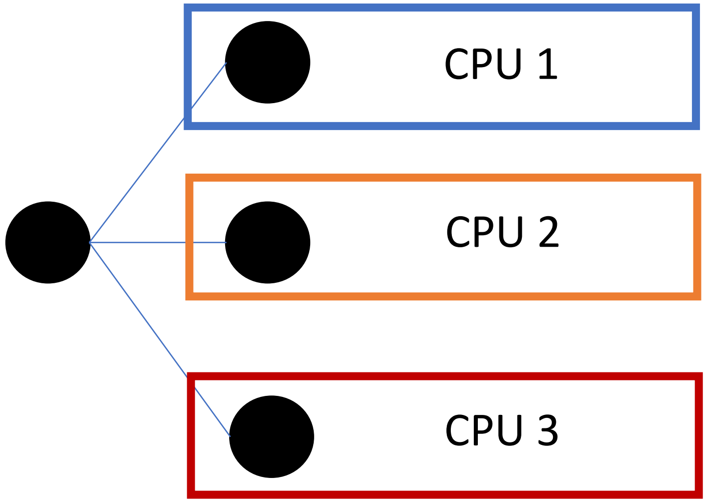
Improve approximation of the economic dispatch (add cuts to the value function)

Proposition

The second stage relaxation algorithm:

- Converges to the optimal value
- Terminates after finitely many iterations

Parallelization



- Each uncertainty scenario is handled by a different CPU
- We have 35 uncertainty conditions in total, we use 35 CPUs

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Results

Tested algorithms

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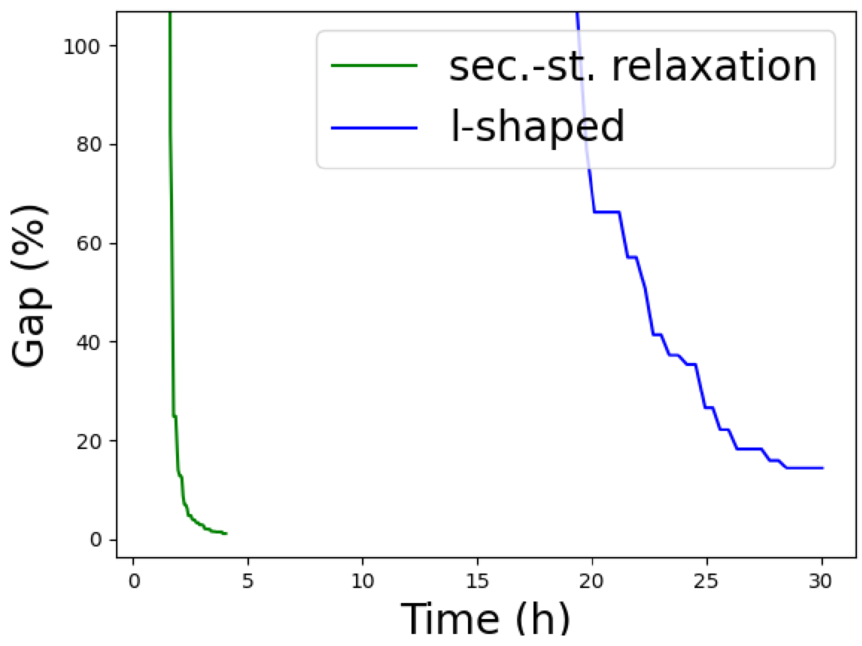
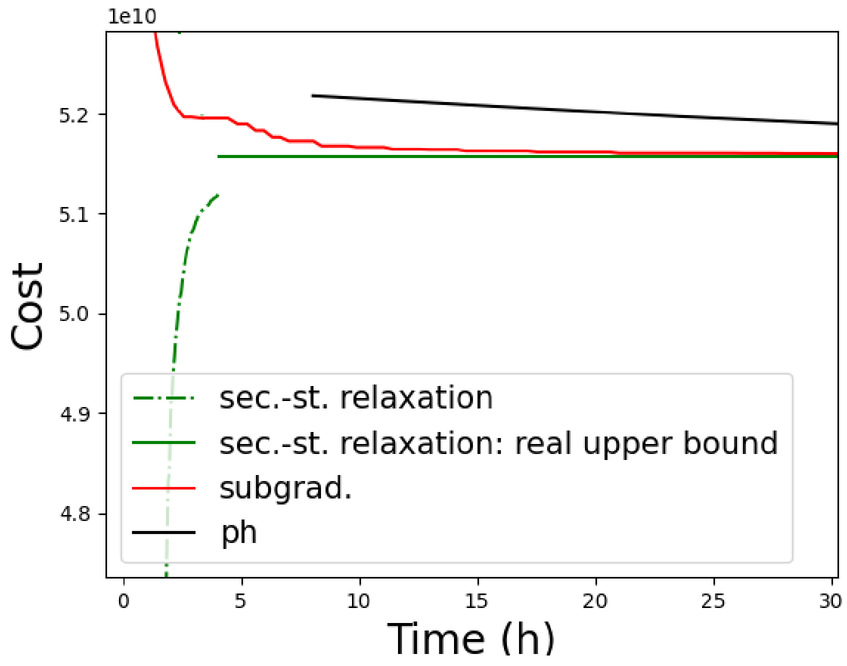
- L-shaped algorithm
- Progressive hedging algorithm
- Projective sub-gradient based methods
- Column-constraint generation-based algorithms (quantitative argument)

Each **algorithm** is run against **our approach,** with the exact **same parameters.**

Convergence evolution (35 CPUs)





Gap evolution: Sec.-st. relaxation and L-Shaped.

Upper bound evolution: Sec.-st. relaxation, subgradient, progressive hedging.

Value stochastic solution

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- **WS**: wait-and-see solution, is the best solution if we perfectly anticipate the climatic conditions
- **SP:** stochastic solution, we obtain an expansion plan that doesn't know exactly what's the climatic condition that will realize(what we compute)
- **Av WS:** average the expansion plans corresponding to perfectly anticipated climatic conditions (what ENTSO-E computed for ERAA 2021)

WS <= SP <= Av WS

Value stochastic solution

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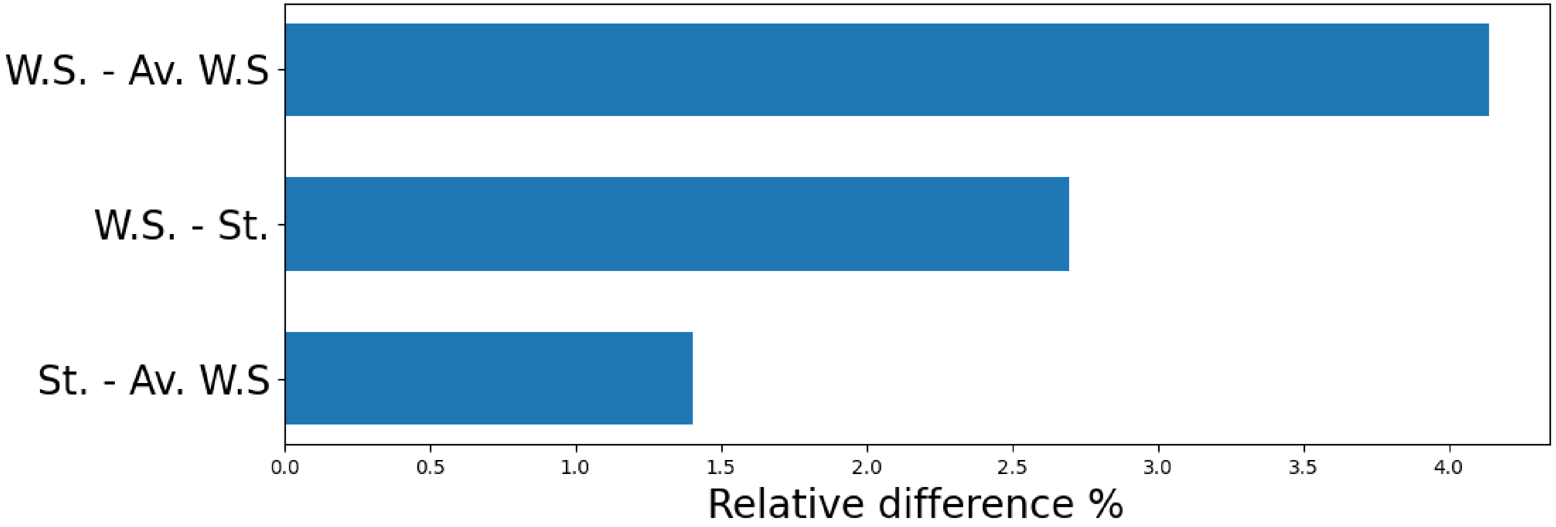


Total cost difference between wait-and-see solution, stochastic solution, and average W.S. solution (WS <= SP <= Av WS)

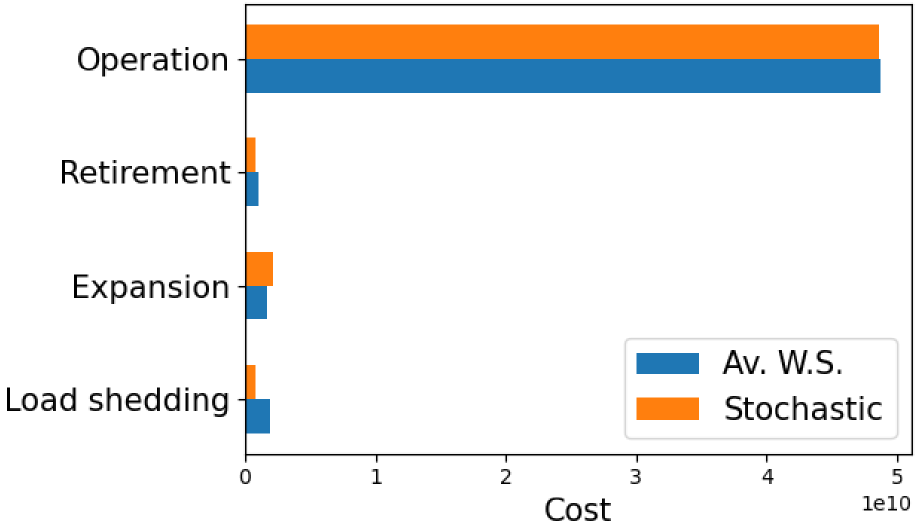
Cost comparison

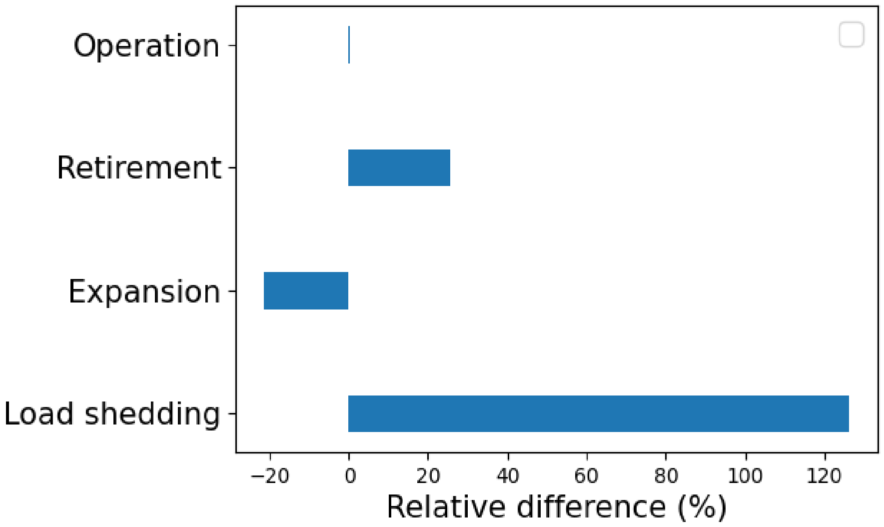
We have two candidate expansion plans:

- **SP:** stochastic solution (what we compute)
- **Av WS:** average the expansion plans corresponding to perfectly anticipated climatic conditions (what ENTSO-E computed for ERAA 2021)

How different are they in terms of costs?

Cost comparison





Costs comparison of stochastic solution against Av WS solution

Adequacy metrics

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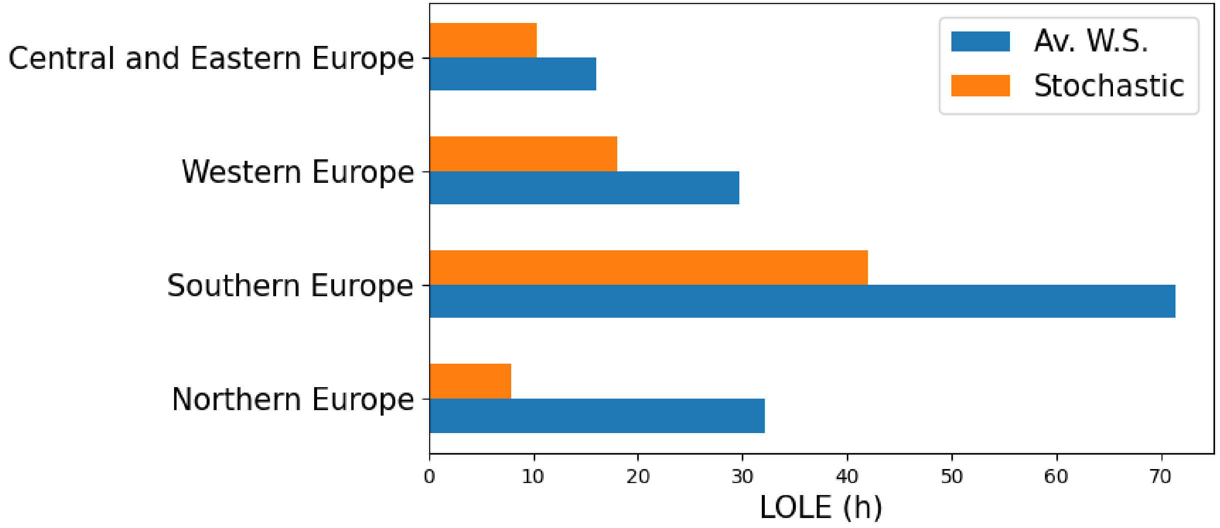

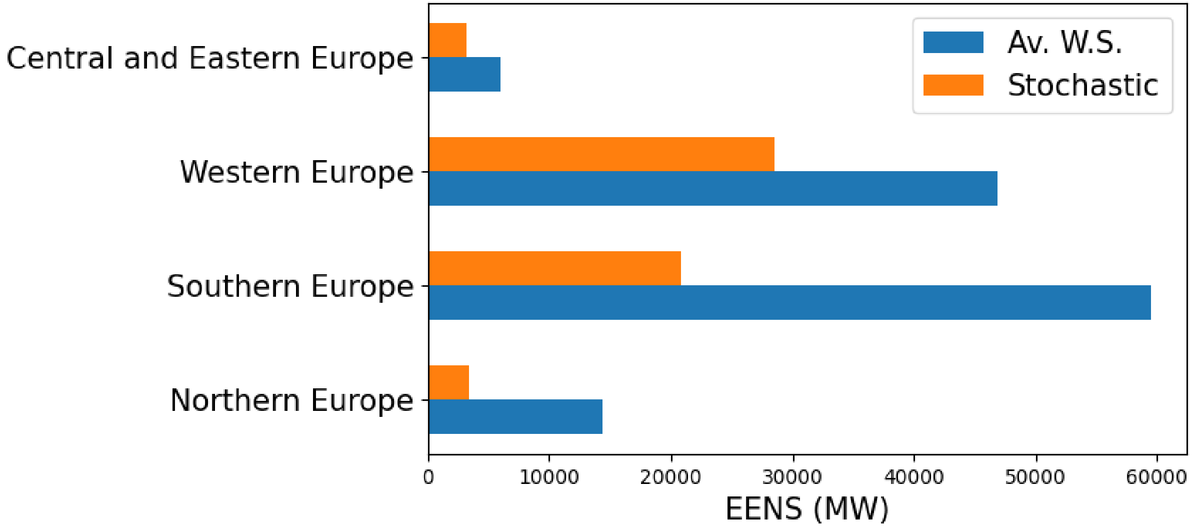

LOLE: Average number of hours where the load was not satisfied in a year

EENS: Average load not satisfied in a year

Contributions

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Methodological contribution

- By means of decomposition schemes and parallel computing, it is possible to solve the Economic Viability Assessment (EVA) of the European Resource Adequacy Assessment (ERAA) 2021 edition

Algorithmic contribution

- Projective subgradient algorithm
- Second-stage relaxation scheme, which converges faster than L-Shaped, progressive hedging, projective sub-gradient
- Parallel implementations for these algorithms

Contributions

Policy contribution

- Analysis of the impact that approximated approaches, as the one used for ERAA 2021, have in the overall solution
- In particular, there are differences when examining adequacy metrics, which are relevant for the ERAA study purposes

Future work

- Multi-year approach
- **Reliability constraints (Nice work from Marilena in the next presentation)**
- Is cost-system minimization what we want to solve?

Thanks!