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FlexPlan

January 25th, 2023

# Planning results for the Italian Regional Case

Marco Rossi, Izabella Faifer, Matteo Rossini

# Agenda

- Power system modelling
- Details of the scenario
- Planning tool testing and model simplifications
- Results of the planning process
- Role of storage and demand flexibility

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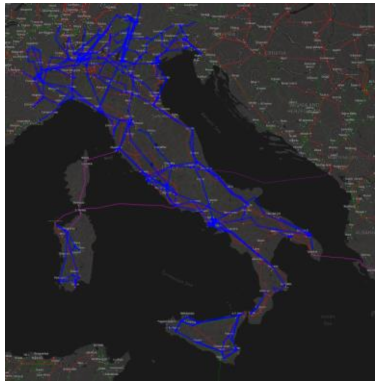
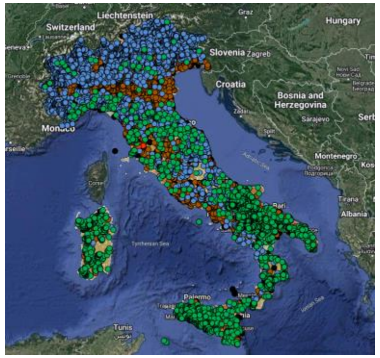
# Power system modelling
## Transmission network model



**Transmisison System model**
ENTSO-E

**Atlarete**
Ministero della
Transizione Ecologica

**Open Infrastructure Map**
Open Street Map



**Renewable power plants**
ATLAIMPIANTI - GSE

**Italian transmission network model**
- 3’166 AC buses (HV)
- 4’071 AC lines (HV)
- 302 HV Transformer stations
- 2 HVDC lines (borders excluded)
- 2’046 primary substations

Transparency Platform

**Data for model validation**
ENTSO-E TP

# Power system modelling

## Distribution network model (medium voltage)

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e-distribuzione provided statistics of distribution network topology and impedance

Synthetic distribution networks are generated

Level of congestion is estimated for each distribution grid

Grid reduction performed in order to considered congested areas only

Distribution networks is integrated into the transmission model

PDF

G. Viganò, M. Rossi, C. Michelangeli and D. Moneta, "Creation of the Italian Distribution System Scenario by Using Synthetic Artificial Networks" 2020 AEIT International Annual Conference, 2020, pp. 1-6

**Italian distribution network model**

- 2'046 primary substations
- 3'604 distribution transformers
- 712'732 AC nodes and lines

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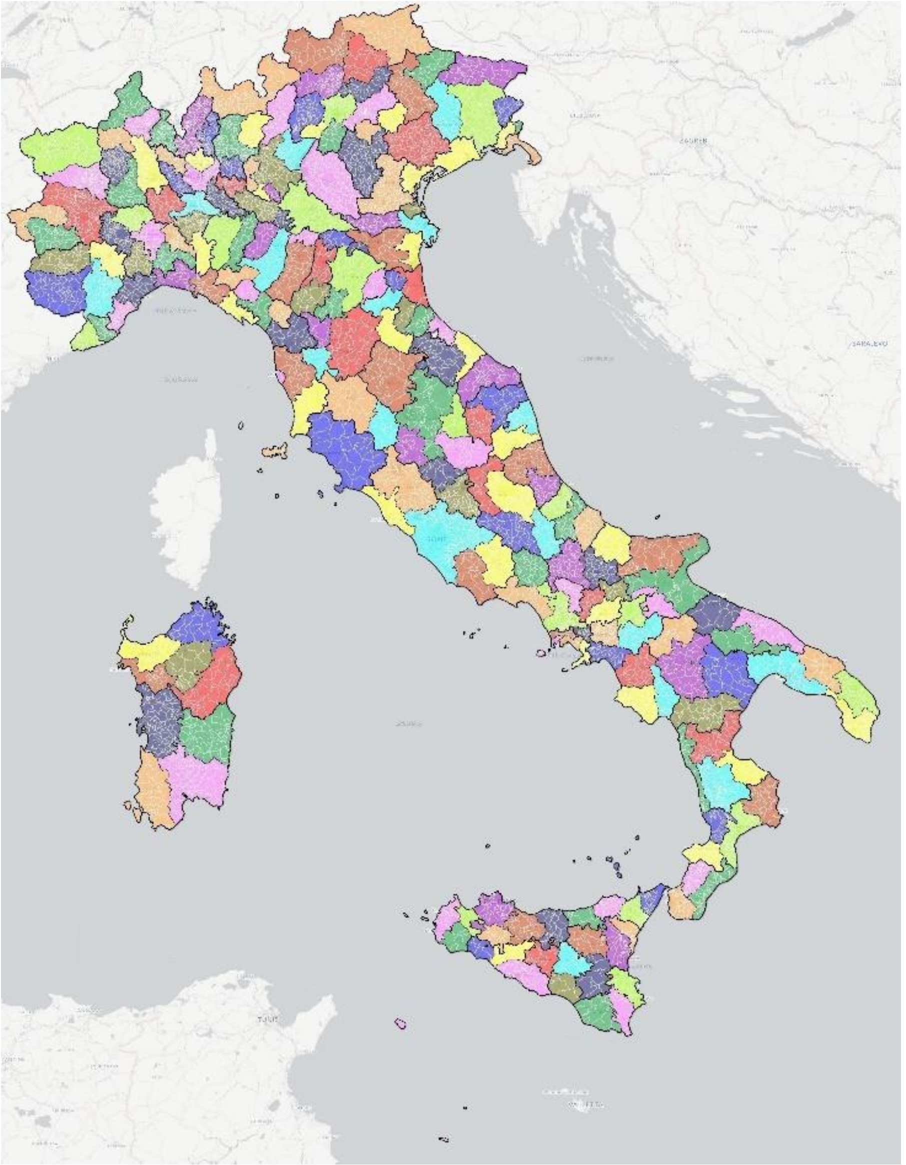
# Details of the scenario

## Model of International Energy Systems

C. Spieker, J. Teuwsen, V. Liebenau, S. C. Müller and C. Rehtanz, "European Electricity Market Simulation for Future Scenarios with High Renewable Energy Production" PowerTech 2015, June 2015.



MILES (Model of International Energy System) is used in order to process ENTSO-E scenario data and to geographically allocate energy resources over the Italian territory (NUTS-3 resolution).

It uses:

- **ENTSO-e scenario data for 2030, 2040, 2050:**
  - **Distributed Energy scenario**
  - **Global Ambition scenario**
  - **National Trend scenario**
- **Annual Mean Capacity Factor [%]**
- **Commodity prices**
- **Reserves (2030)**
- **Net Transfer Capacities (2030)**

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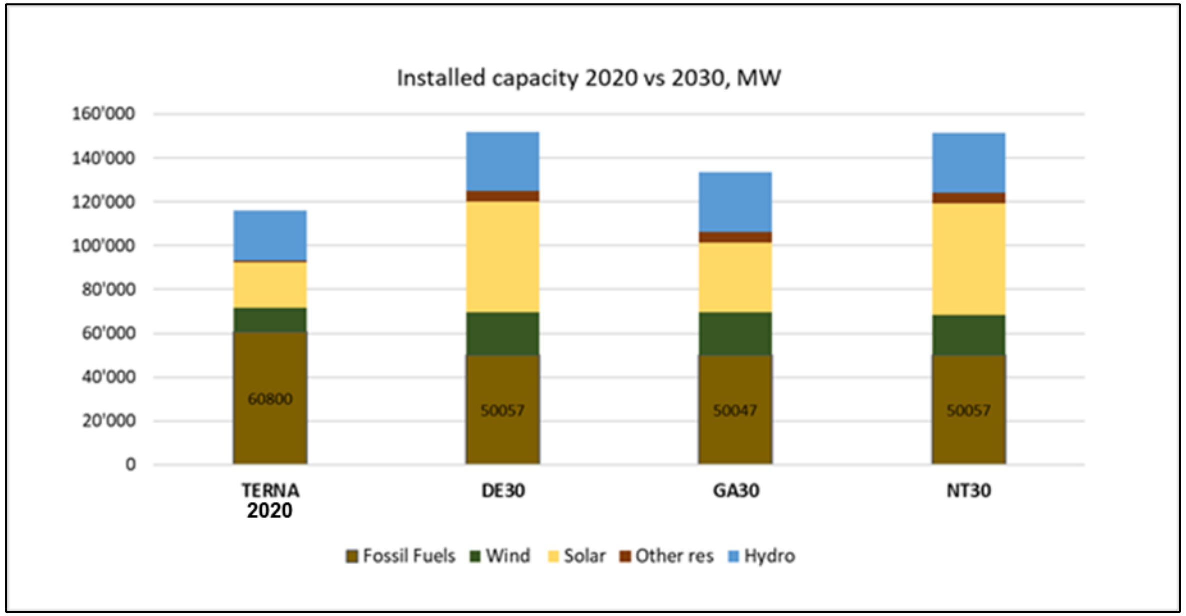
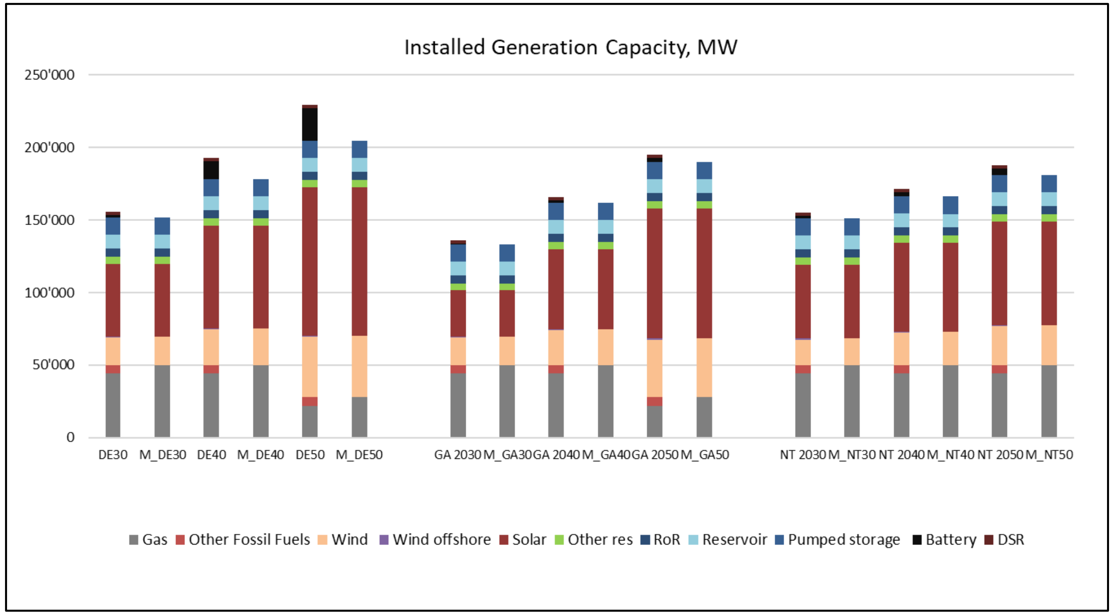
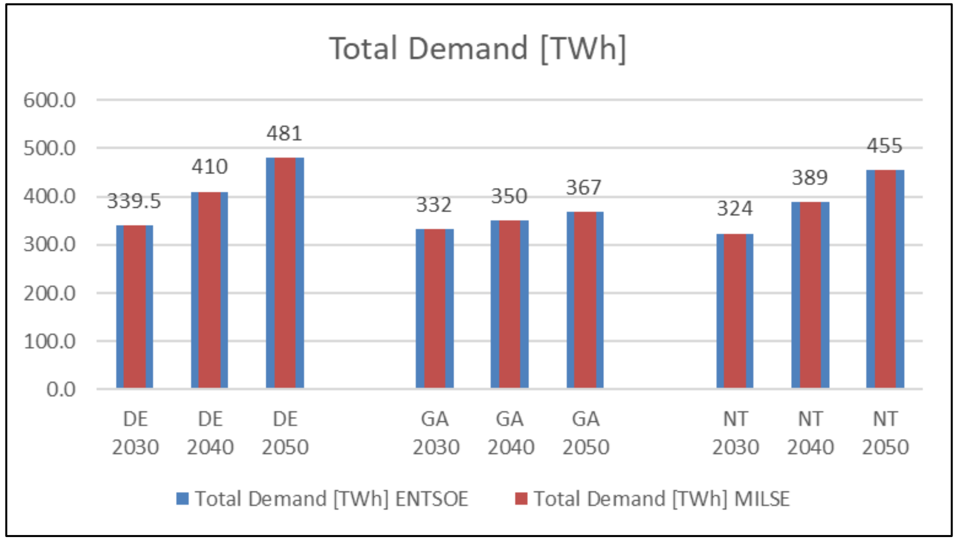
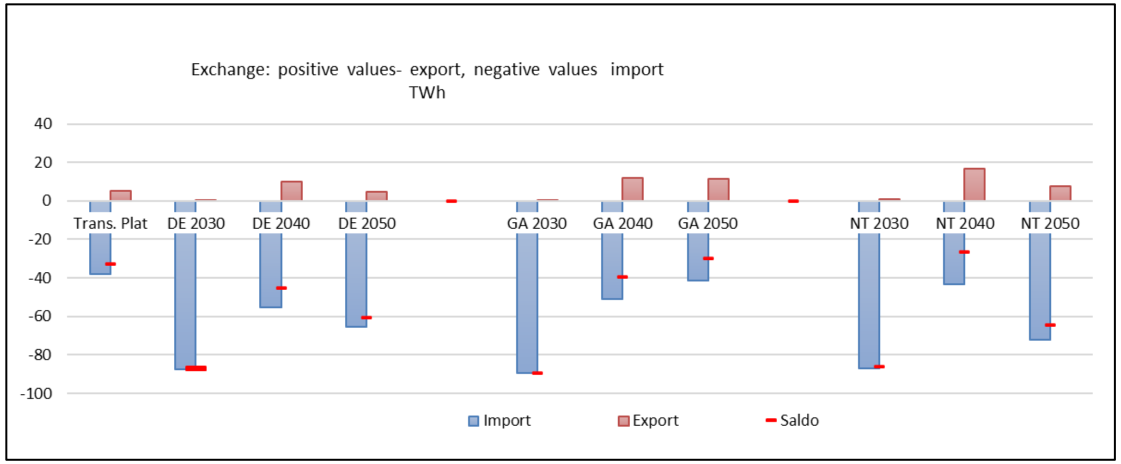
# Details of the scenario

## Comparison of generation mix, demand, border exchanges



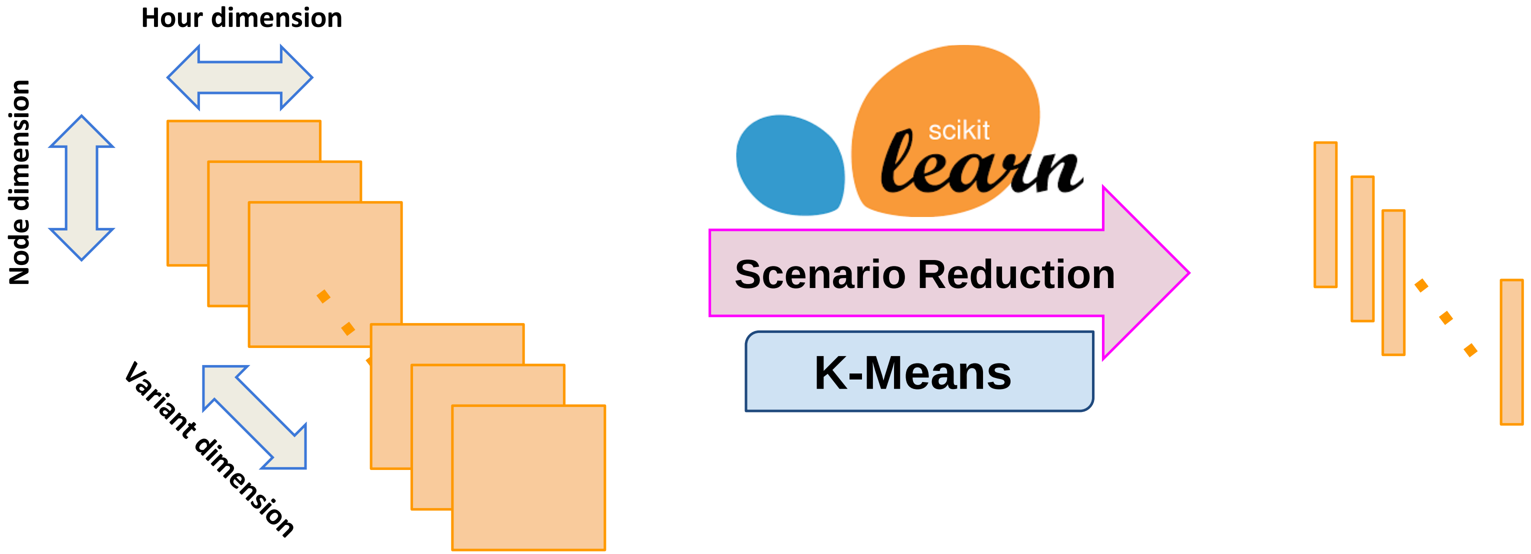



# Details of the scenario

## Scenario reduction




35 variants * 8760 hours

Time profiles of 35 climate variants for each decade (2030-40-50) and scenario (DE,GA,NT)

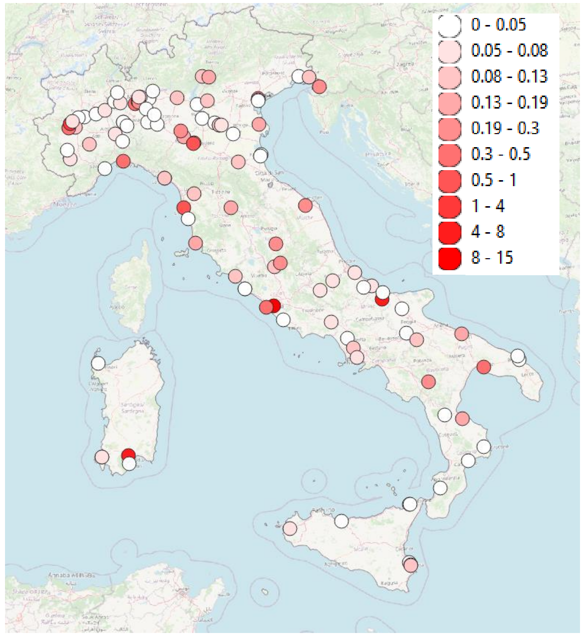
5 variants * 12 weeks * 168 hours

- 5 representative climate variants (with different probabilities)
- 12 representative weeks (one for each month of the year)
- Time resolution: 1 hour (168 time steps per week)

# Details of the scenario
## Environmental impact

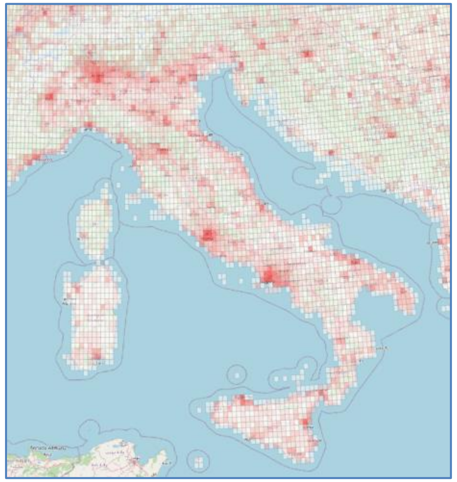
Health impact (YOLL/µg·m$^{-3}$)
Cost (€/YOLL)
Reference production (MWh)

### Air quality impact cost (€/MWh)

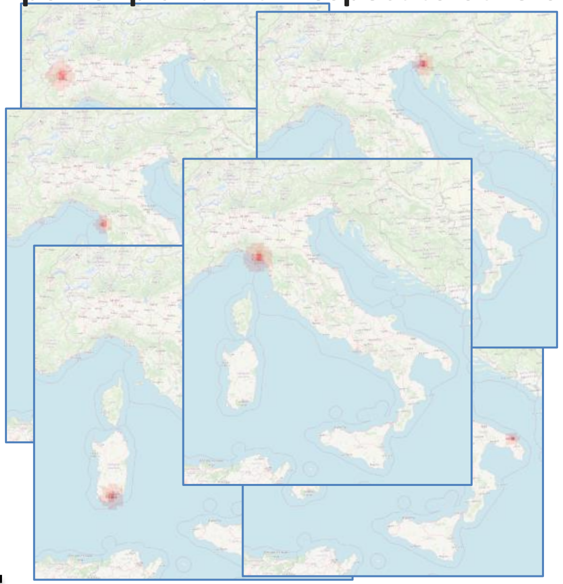



Impact areas around power plants (25 km radius)

Resident population



Weighting factor of individual power plant with respect to others



Pollutant concentration cumulative impact due to all generators, estimated with air quality simulations

# Details of the scenario

## Carbon footprint

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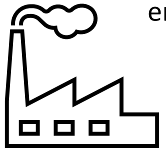
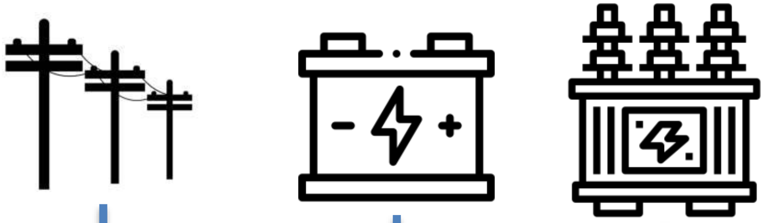
direct CO2 eq. emissions

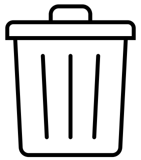


PV production, transportarion

**Planning investments**



direct CO2 eq. emissions



dismantling and recycling

**2750÷3500** kg of $CO_2$*$km^{-1}$*$year^{-1}$

**114÷173** kg of $CO_2$*$km^{-1}$*$year^{-1}$

**100÷900** kg of $CO_2$*$MVA^{-1}$*$year^{-1}$

**Climate change avoidance costs**
**€/t$CO_2$ equivalent (€2016)**

| | Low | Central | High |
|---|---|---|---|
| $CO_2$ Emissions – short and medium run (until 2030) | 60 | 100 | 189 |
| $CO_2$ Emissions – long run (from 2040 to 2060) | 156 | 269 | 498 |

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# Agenda

- Power system modelling
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# Planning tool testing and model simplifications

## Grid Expansion Planning (GEP) process


- Role of the **non-expanded Optimal Power Flow**
  - Simulation of the scenario and indication of the level of congestion for grid elements

- Role of **Preprocessor**
  - Identification of potential asset investments aimed at solving congestion (with priorities depending on congestion severity – Lagrange Multipliers)
  - Identification of nodes in which storage/demand flexibility can be beneficial for congestion management (using Locational Marginal Prices)
  - Proposal of storage technology on the basis of characteristics of congestions and territory

- Role of **Planning tool**
  - Returns the list of the candidates which minimizes the total costs (CAPEX+OPEX), and details on their behaviour

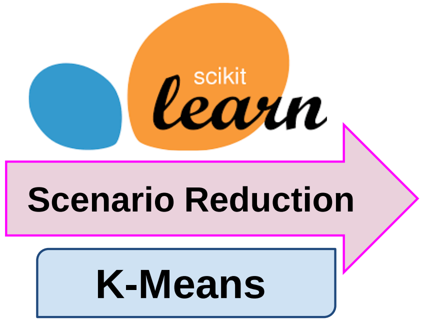
# Planning tool testing and model simplifications

## Dealing with real-size power systems

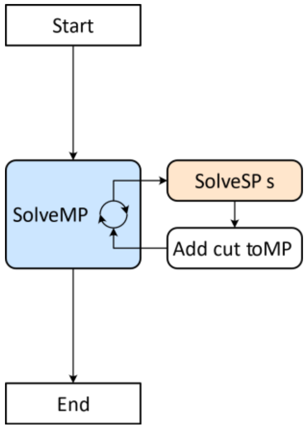
FlexPlan

The development of the planning procedure has been carried out in order to be able to manage:

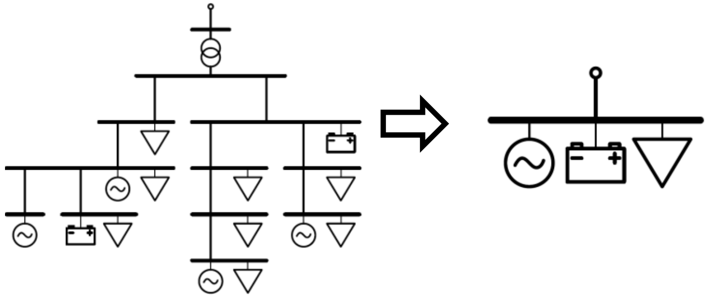
- **Real/size power systems** with more voltage levels simultaneously (transmission, sub-transmission and distribution)
- **Multiple scenarios** to consider both variability of electricity demand and renewable power production (climatic variants)
- **Multiple target years**, to optimally select investments by considering planning impact over their entire lifetime




**Scenario reduction**




**Benders decomposition**



**Transmission & Distribution decomposition**

# Planning tool testing and model simplifications

## Dealing with the limited time/hardware resources of FlexPlan

FlexPlan

Event though the tools have been optimized in order to manage real-size systems, operating in a multitude of scenarios and climate variants, FlexPlan regional cases have been studied by applying some simplifications.

**4 representative weeks**
(instead of 12)

**Reduced time resolution**
(2-hour time blocks)

**Limited portion of Distribution Network**
(10%)

**100 planning candidates**
(20 HV + 80 MV)

Total processing time per reference year
**3÷5 days**

**Relaxed optimality tolerance**
(0.01% MIP-gap)

**1-decade time horizon**
(instead of 3)

**Reduced amount of Transmission AC lines**
(short lines neglected)

**1 climate variant**
(instead of 35)

# Planning tool testing and model simplifications

## Dealing with the limited time/hardware resources of FlexPlan

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**Disclaimers:**

- The objective of the activity consists of **validating the proposed grid expansion planning procedure**, with the resources available for the project.
- The reconstruction of the grid model from **non-certified data sources**, combined with the adopted **simplifications**, could lead to unrealistic results if compared to the actual/expected Italian situation.

With appropriate resources in terms of hardware and computational time, the tool is capable of managing real-size systems with no/less simplifications.

FlexPlan

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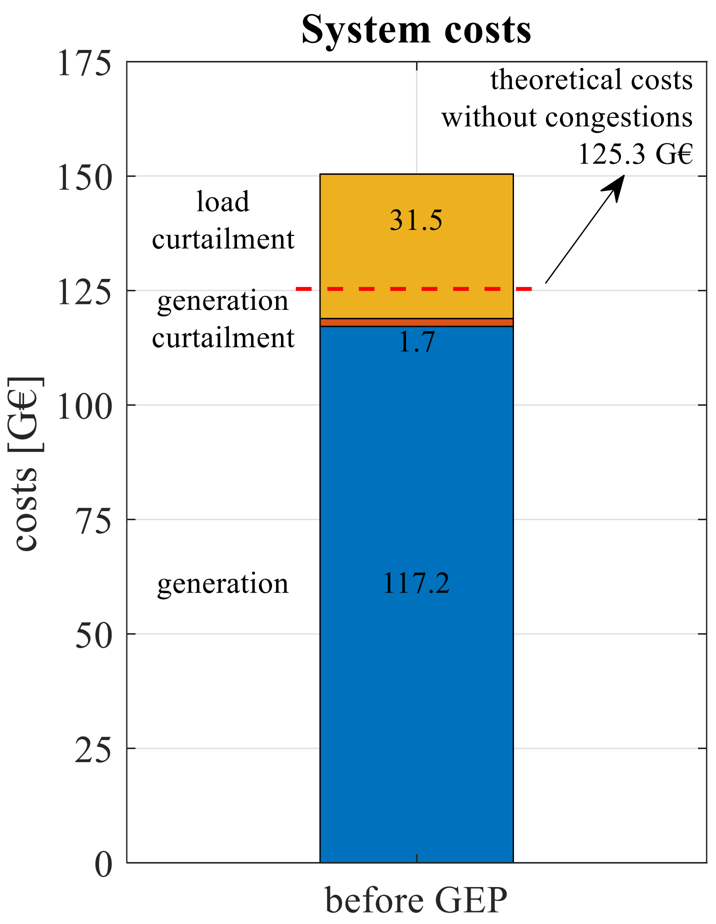
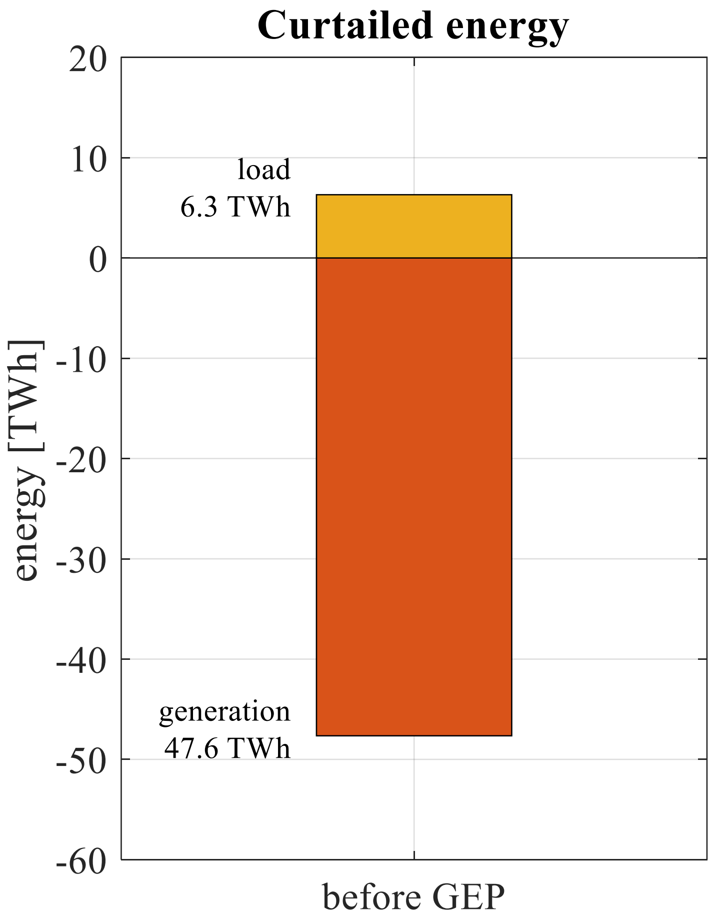
# Results of the planning process

## Non-expanded OPF (objective function) → 2030

Non-expanded OPF consists of a simulation of the energy dispatch model, including:

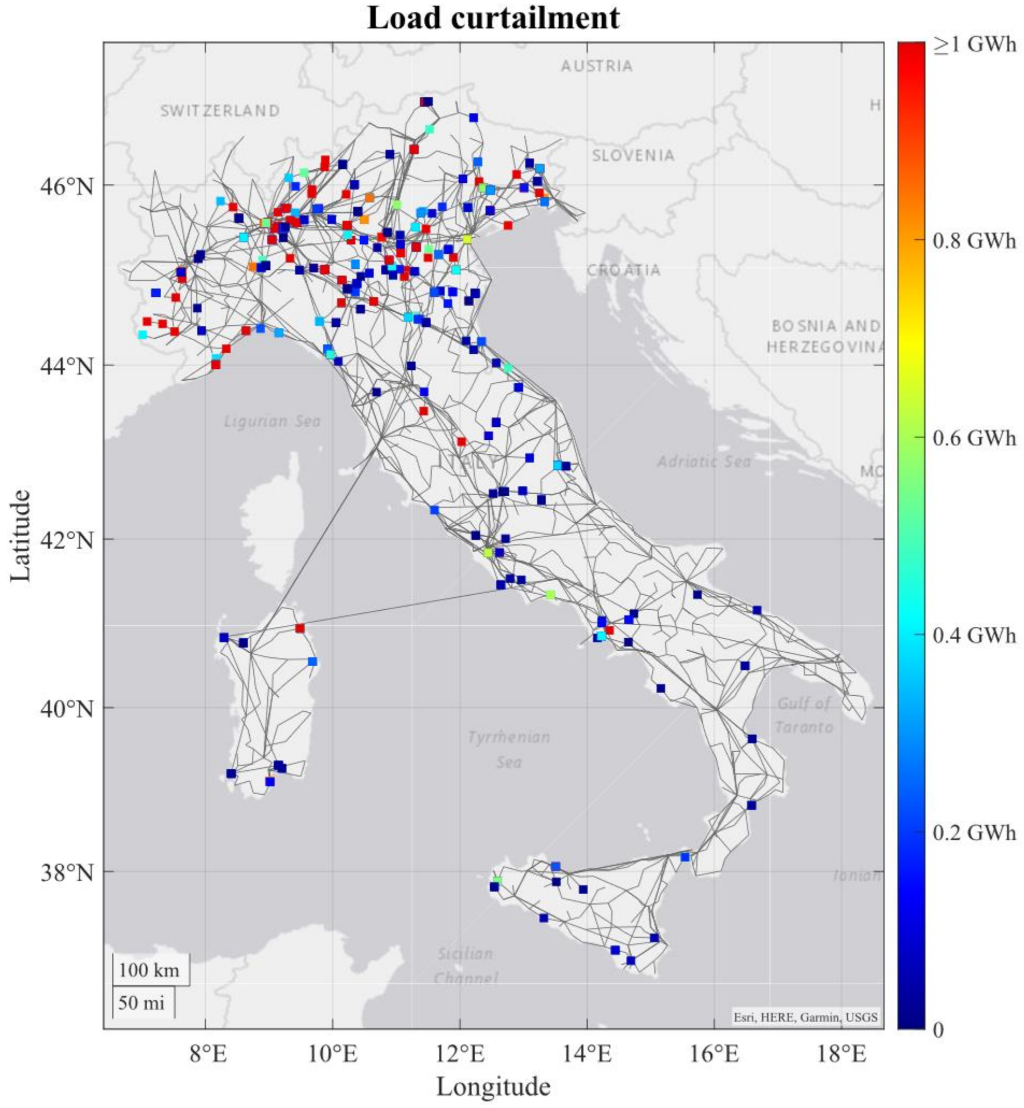
- Electricity generation:
  - Dispatchable generators (fuel costs, environmental impact)
  - Renewable energy resources (curtailment costs 36 €/MWh)
- Electricity transport and distribution
  - Transmission network model (DC OPF)
  - Distribution network model (linearized AC OPF)
- Electricity demand
  - Loads (value of lost load 5000 €/MWh)
- Electricity storage
  - Pumped-hydro storage and water reservoirs (with injection/absorption efficiencies and water inflows)

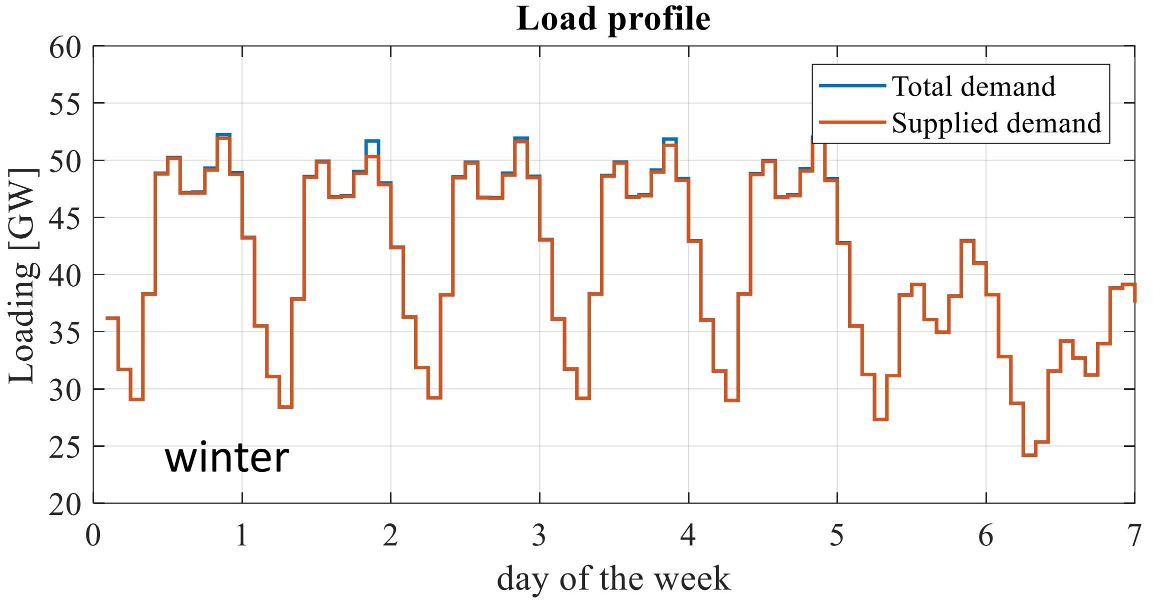


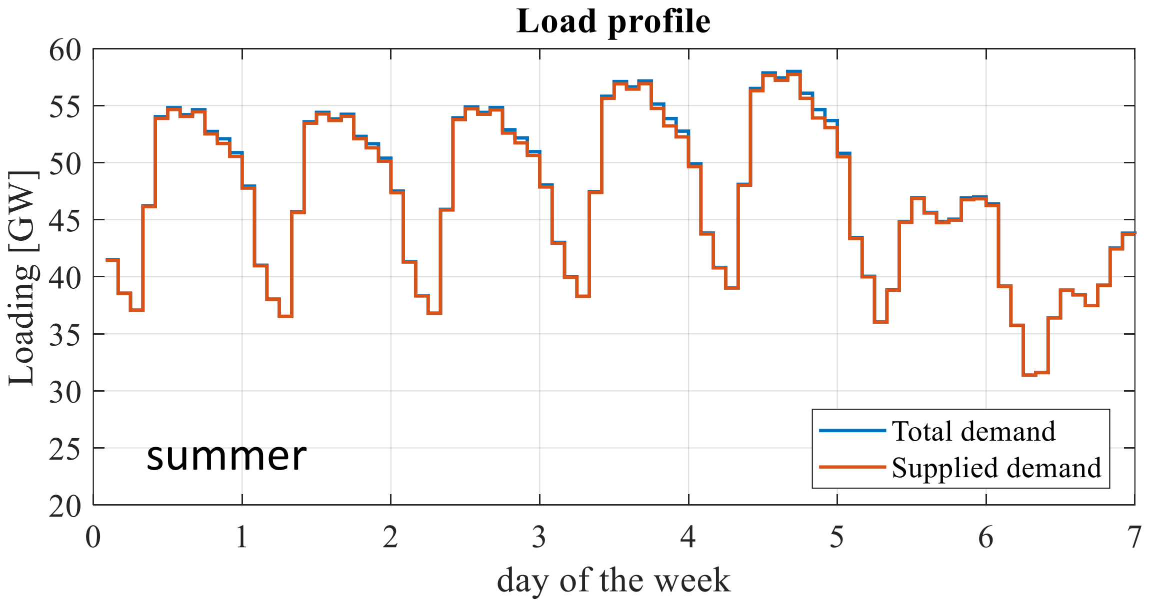



# Results of the planning process

## Non-expanded OPF (load curtailment) → 2030

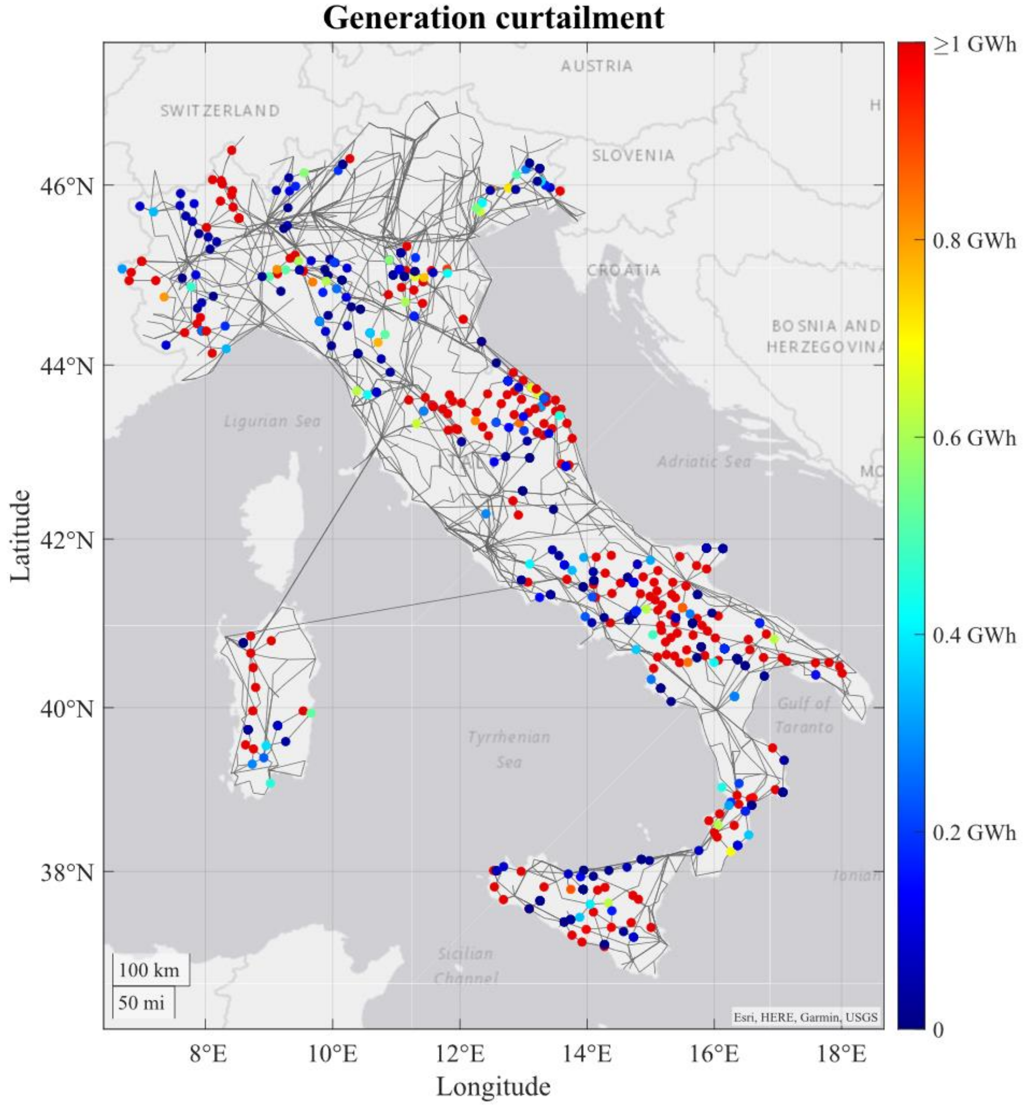


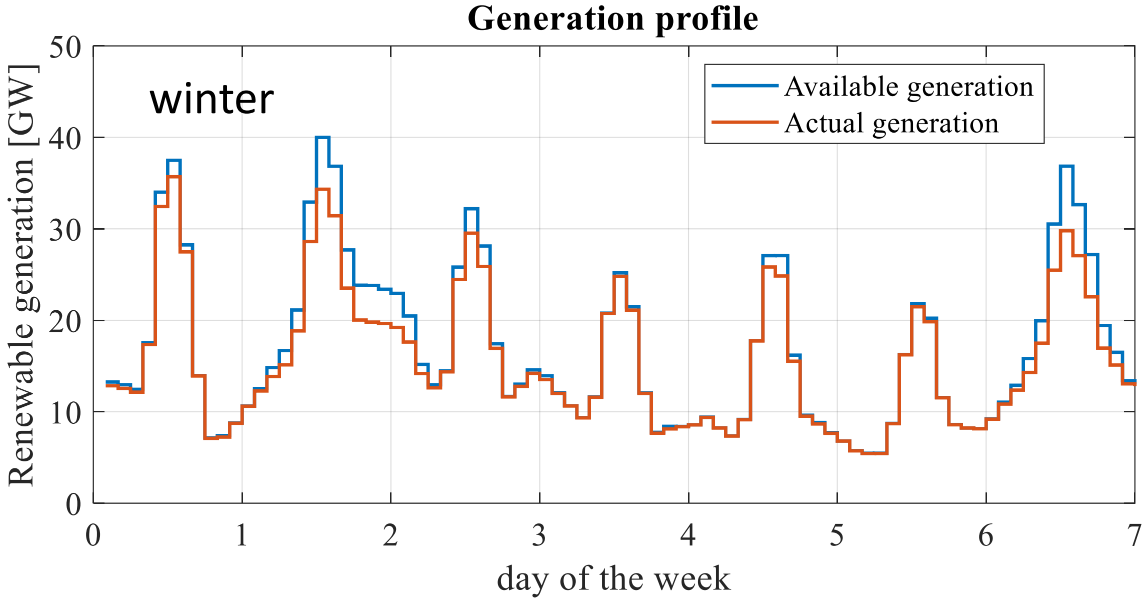



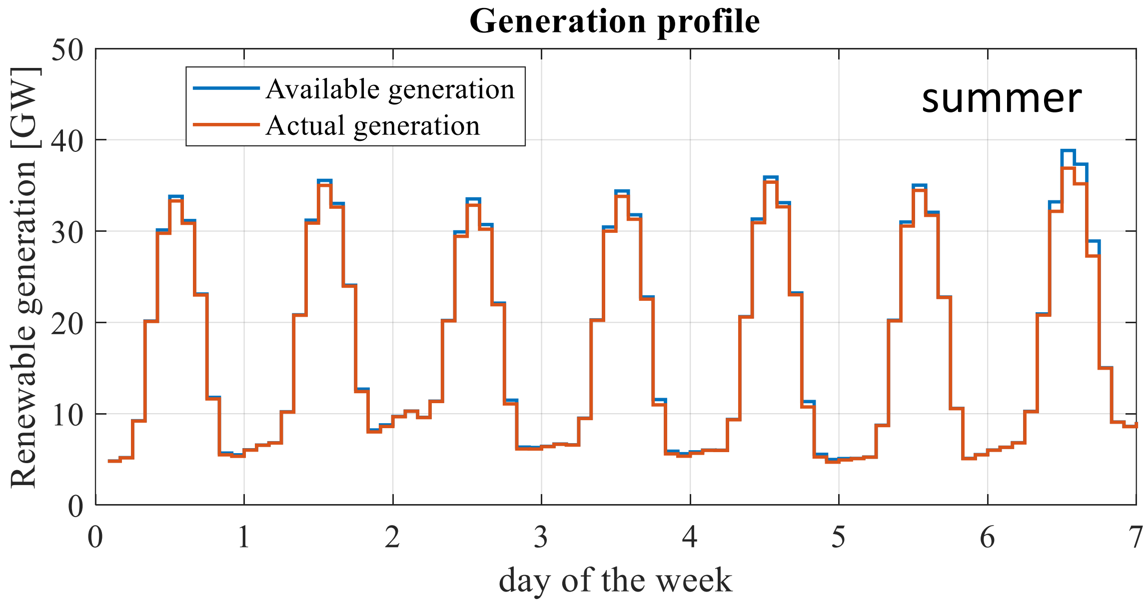



# Results of the planning process

## Non-expanded OPF (Curtailment of renewables) → 2030

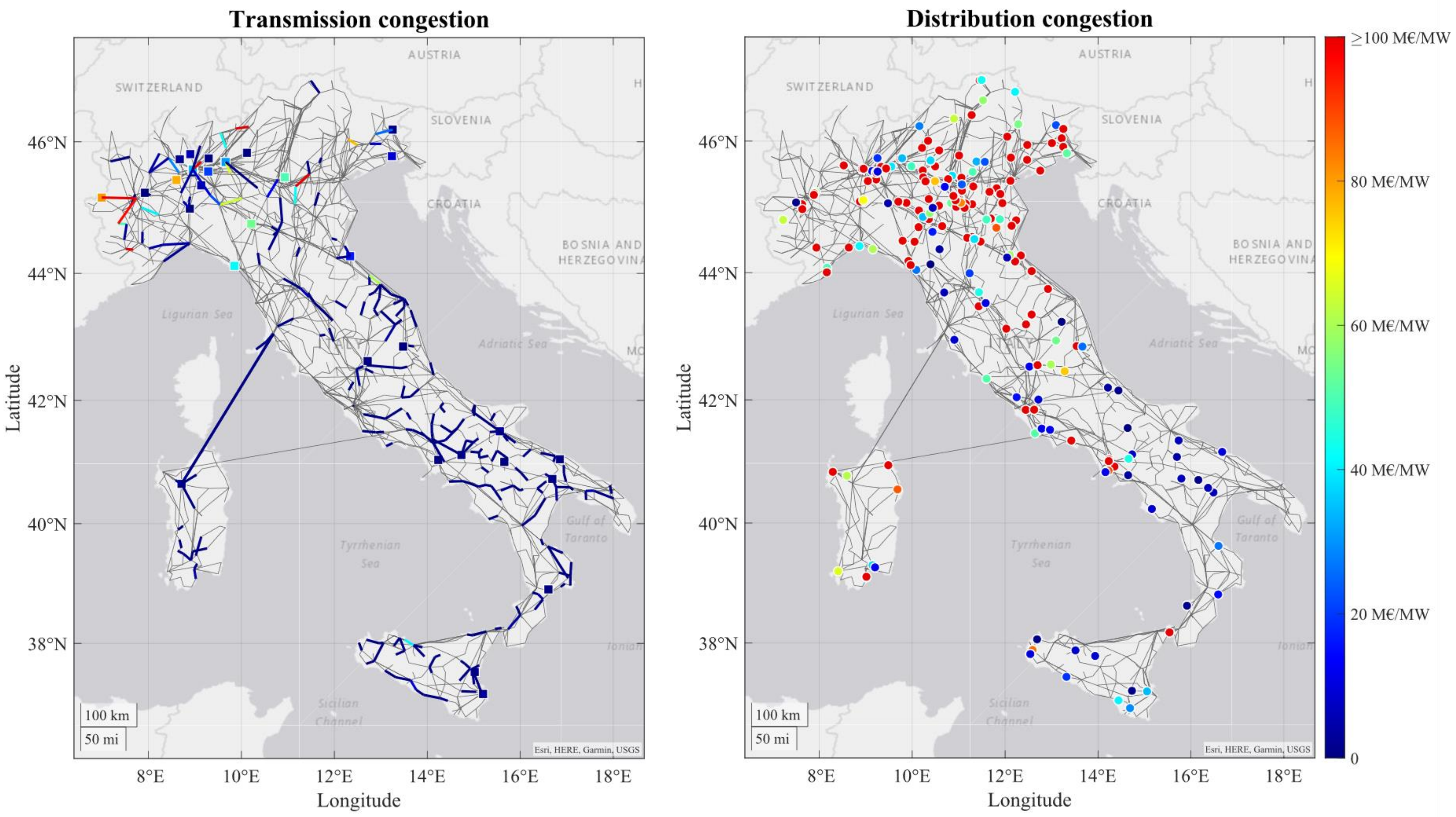


# Results of the planning process

## Non-expanded OPF (congestion severity) → 2030




Non-expanded OPF returns, for each grid element, the **congestion severity**:

- Savings in M€ for each MW (or MVA) in additional capacity of:

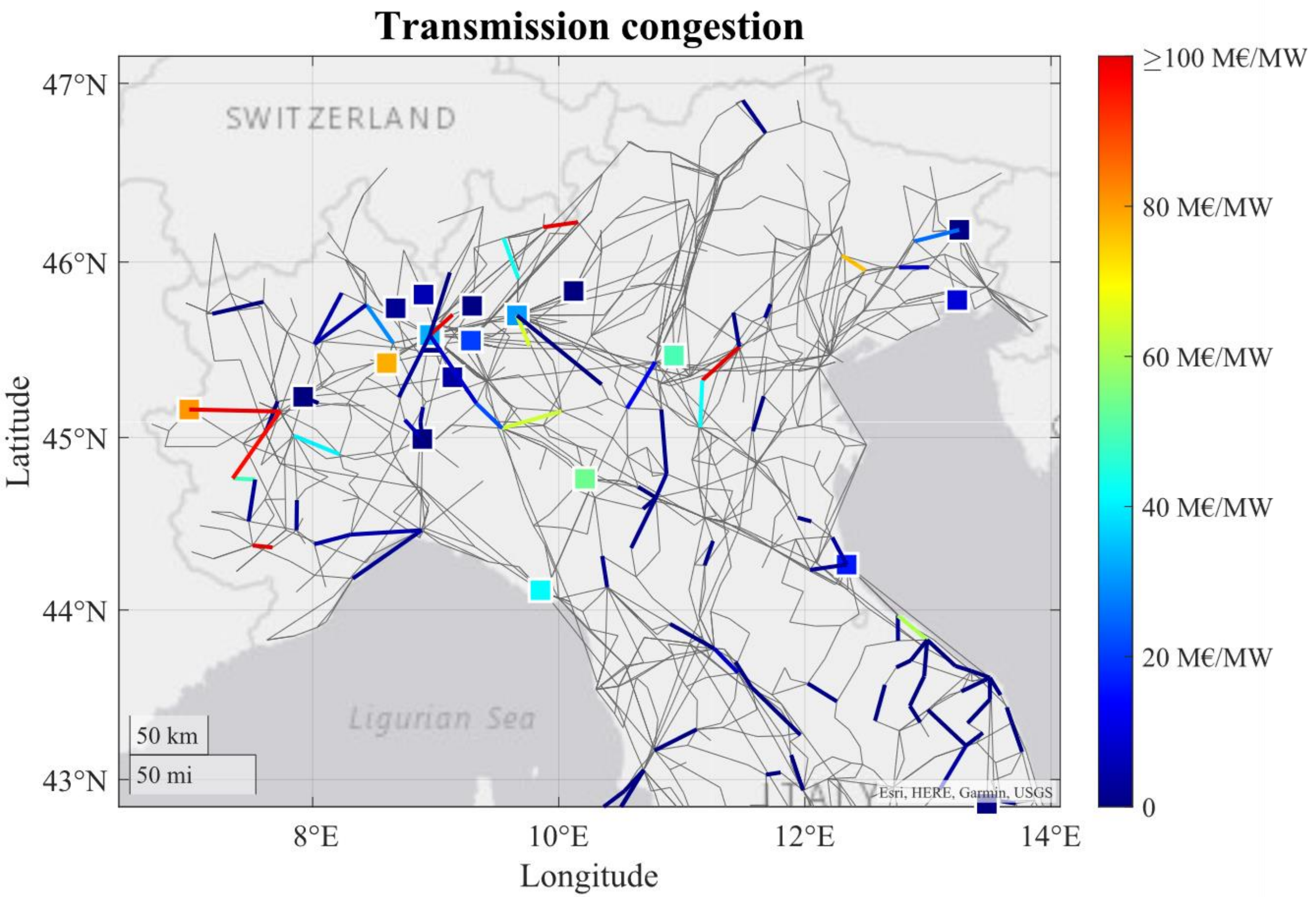
  AC/DC Line

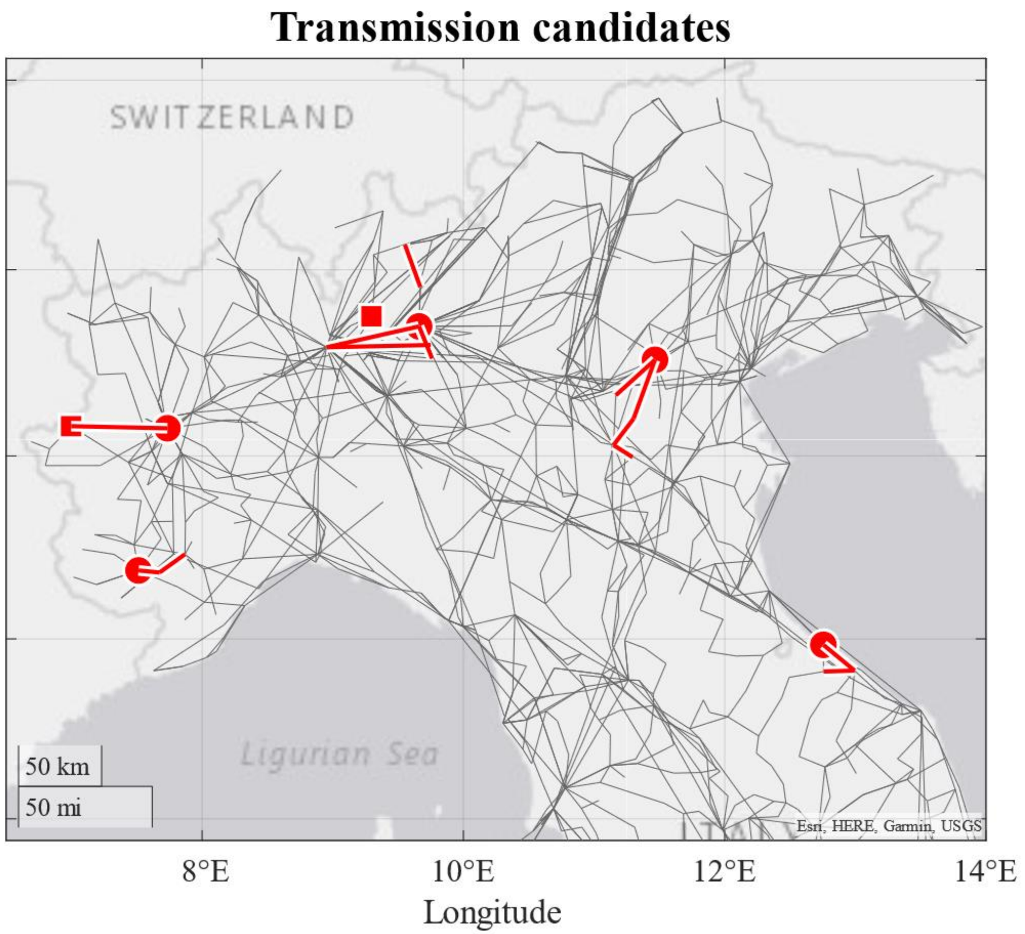
  Transformers

  Distribution network element

# Results of the planning process

## Preprocessor (transmission network candidates) → 2030




AC line reinforcement

Transformer reinforcement

New storage unit

# Results of the planning process

## Preprocessor (distribution network candidates) → 2030

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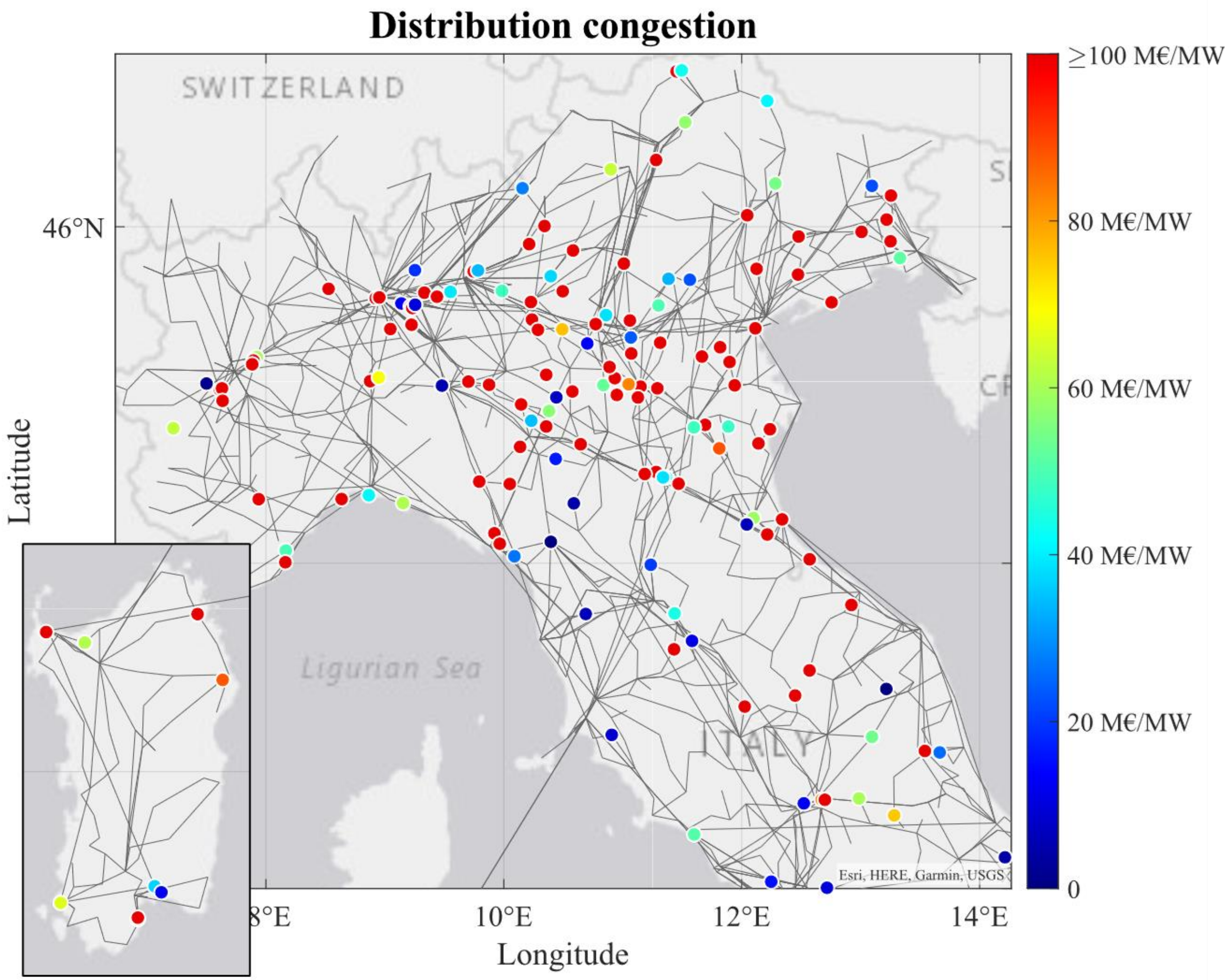
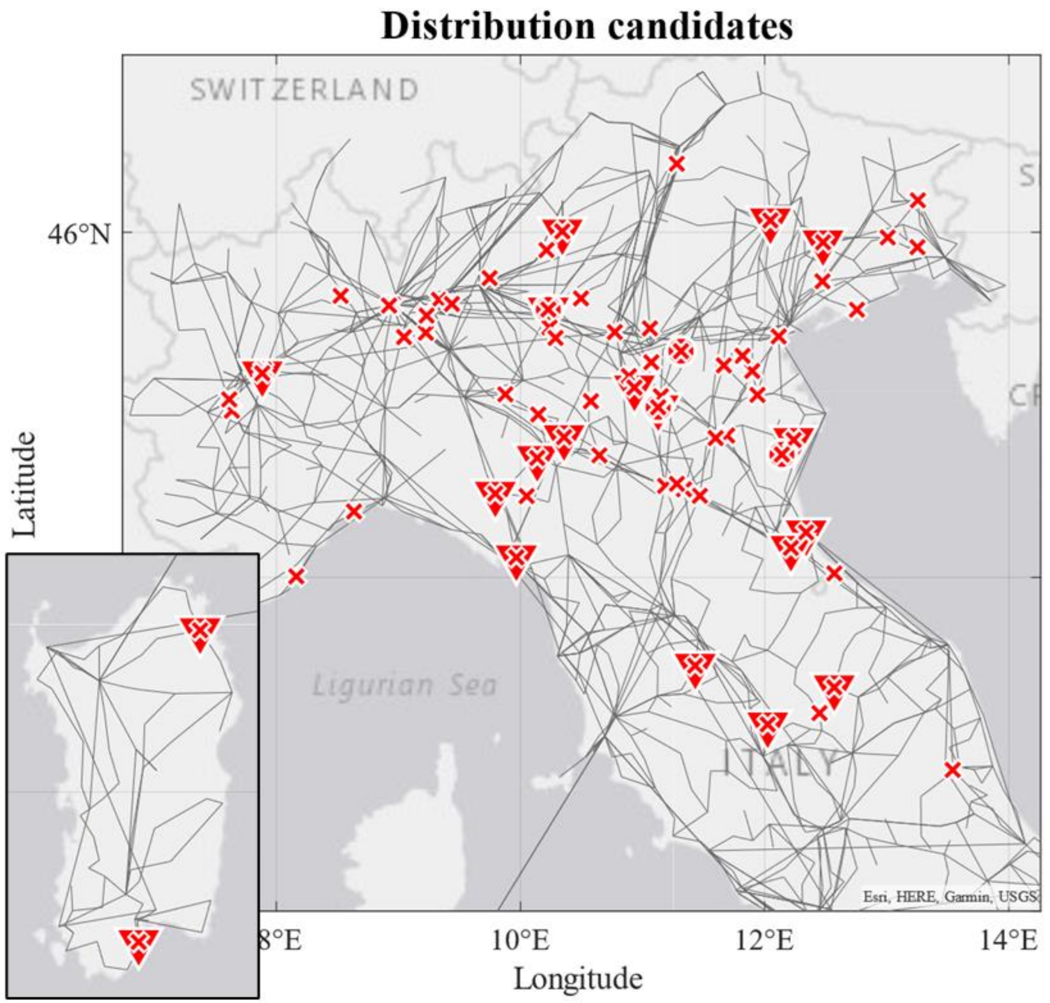



AC line reinforcement

*Flexibilization* of existing load

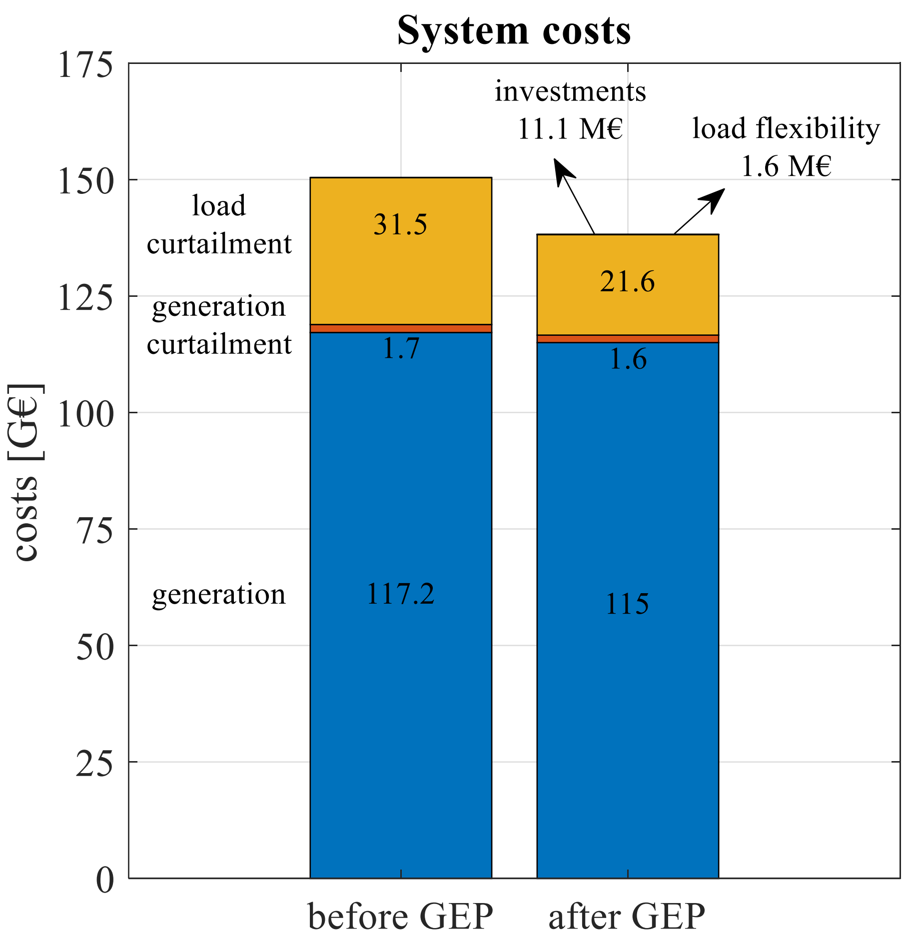
New storage unit

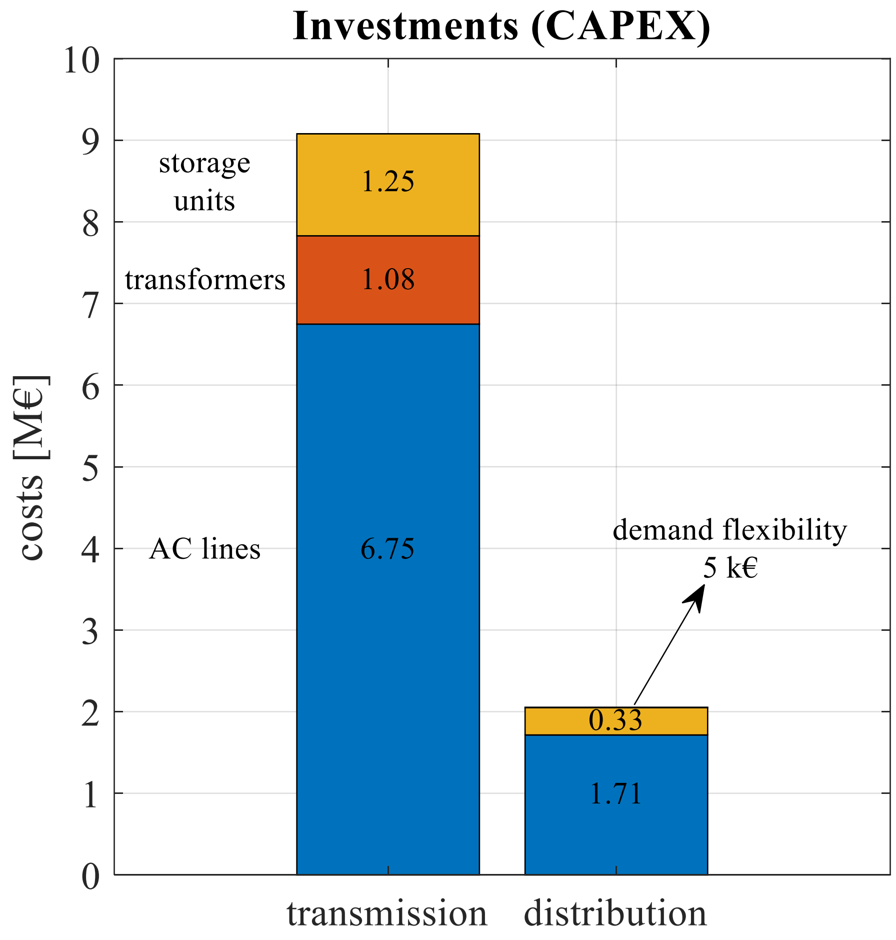
# Results of the planning process

## Grid Expansion Planning (GEP) → 2030

The GEP process solves a mixed-integer optimization problem aimed at minimizing the total expenditure (CAPEX+OPEX) of the system.

(even though a significant portion of load curtailment is avoided, the proposed set of planning candidates is not sufficient to reduce it to acceptable values)



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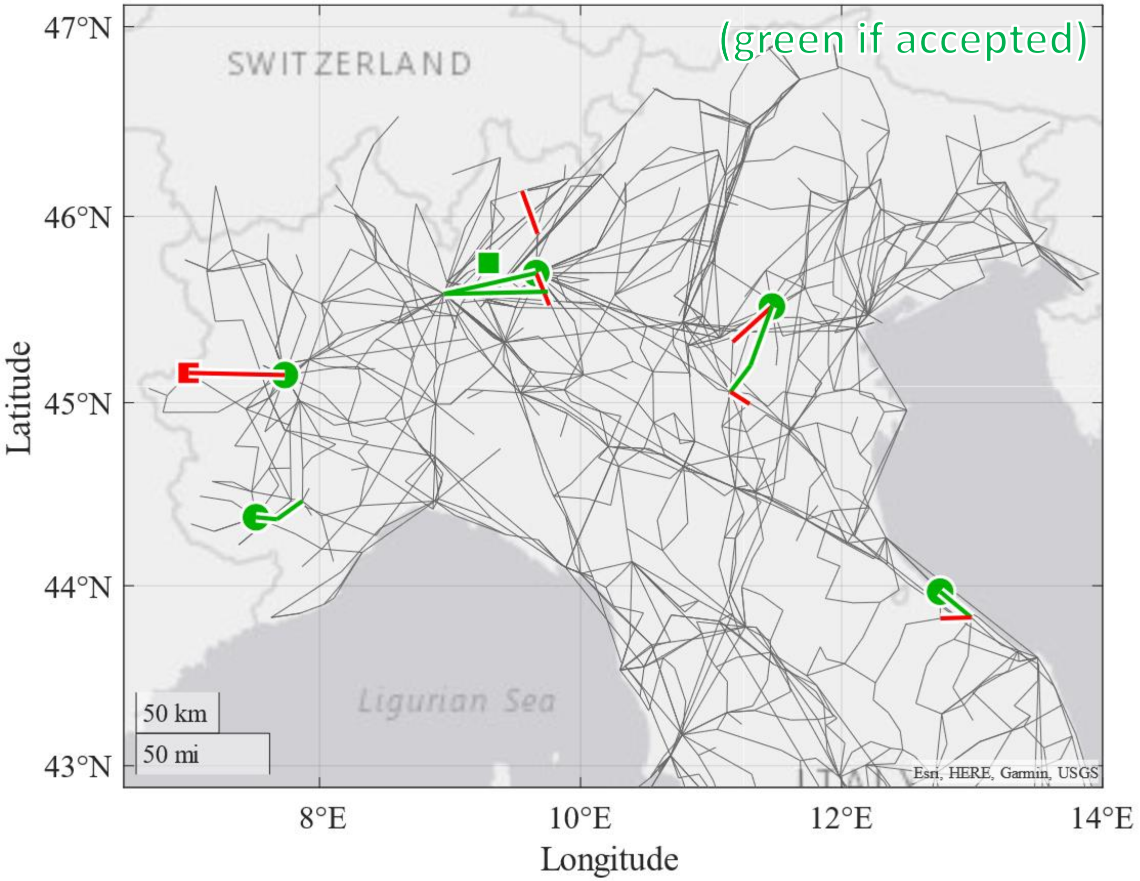
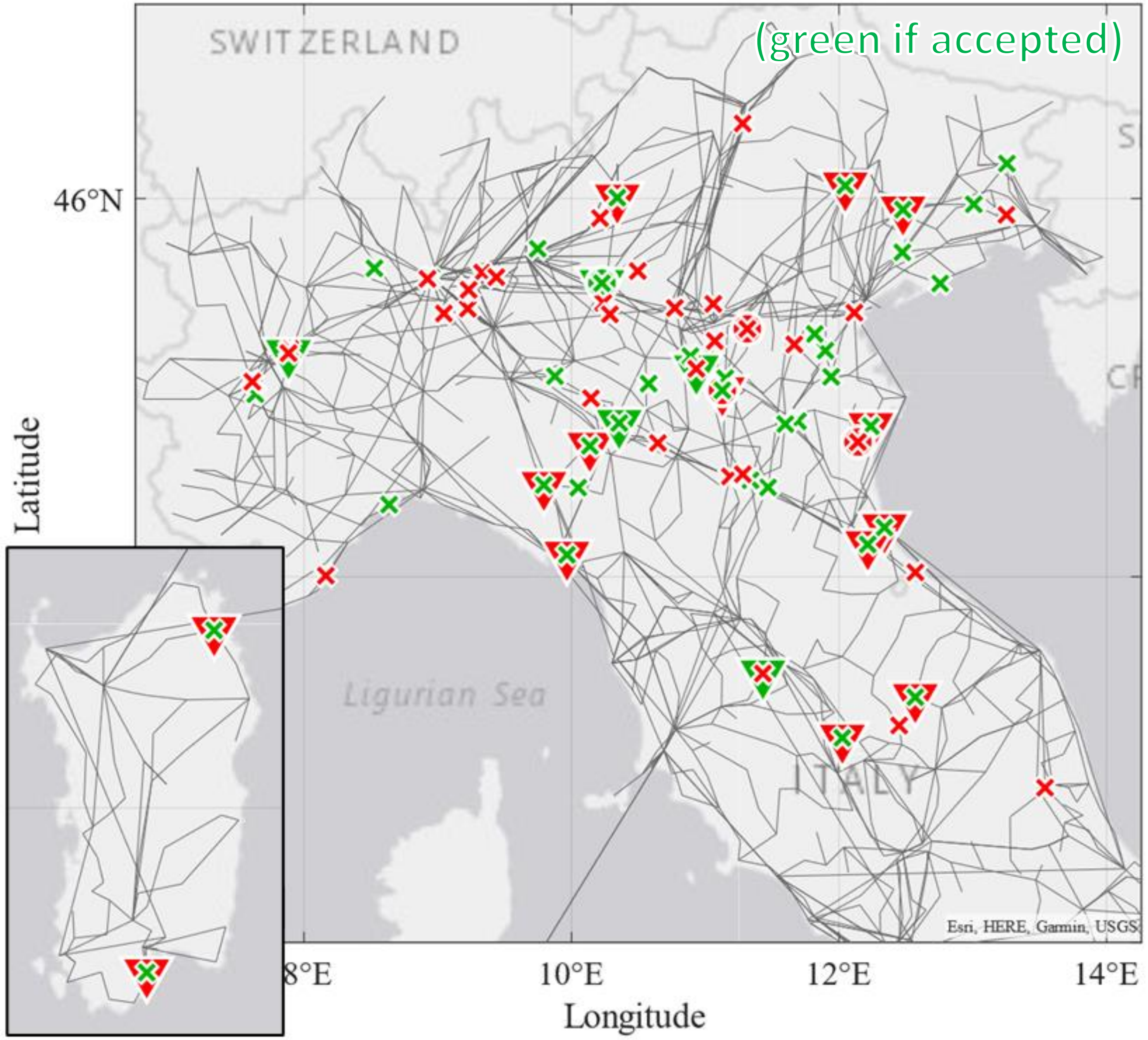
# Results of the planning process

## Grid Expansion Planning (GEP) → 2030

**Transmission candidates**




**Distribution candidates**




AC line reinforcement

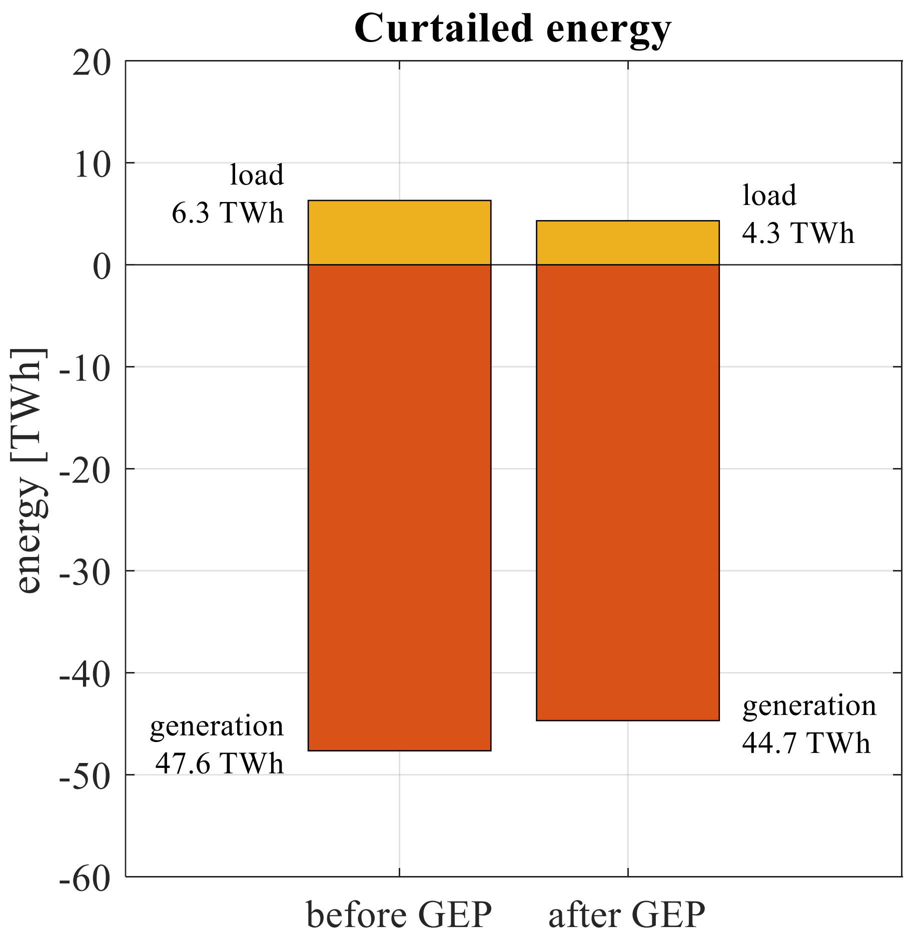
Transformer reinforcement

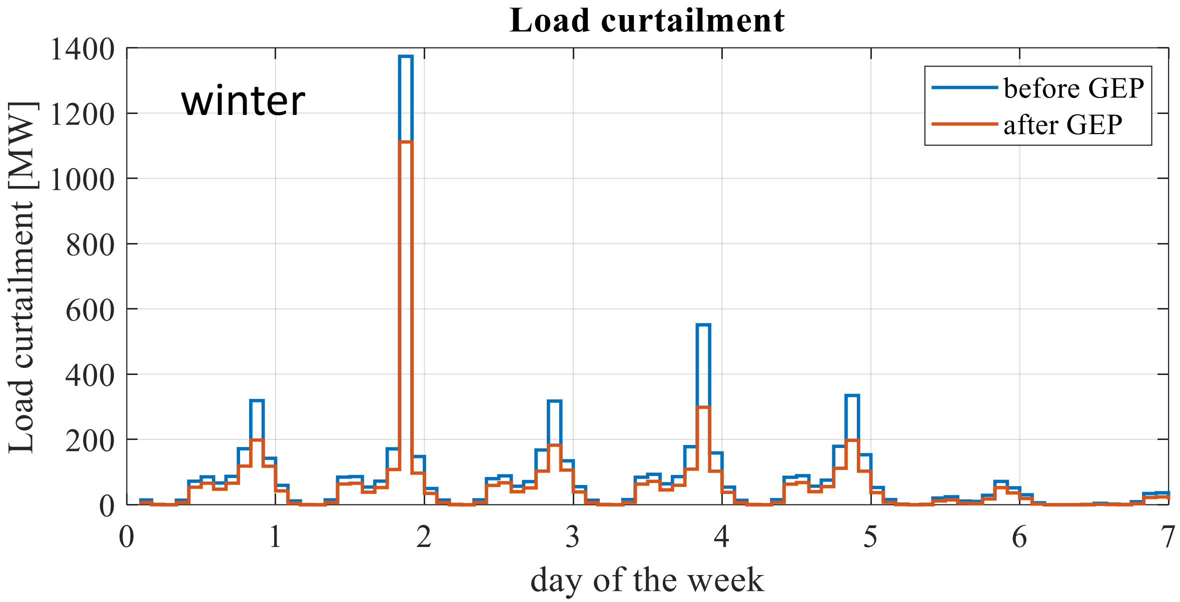
*Flexibilization* of existing load

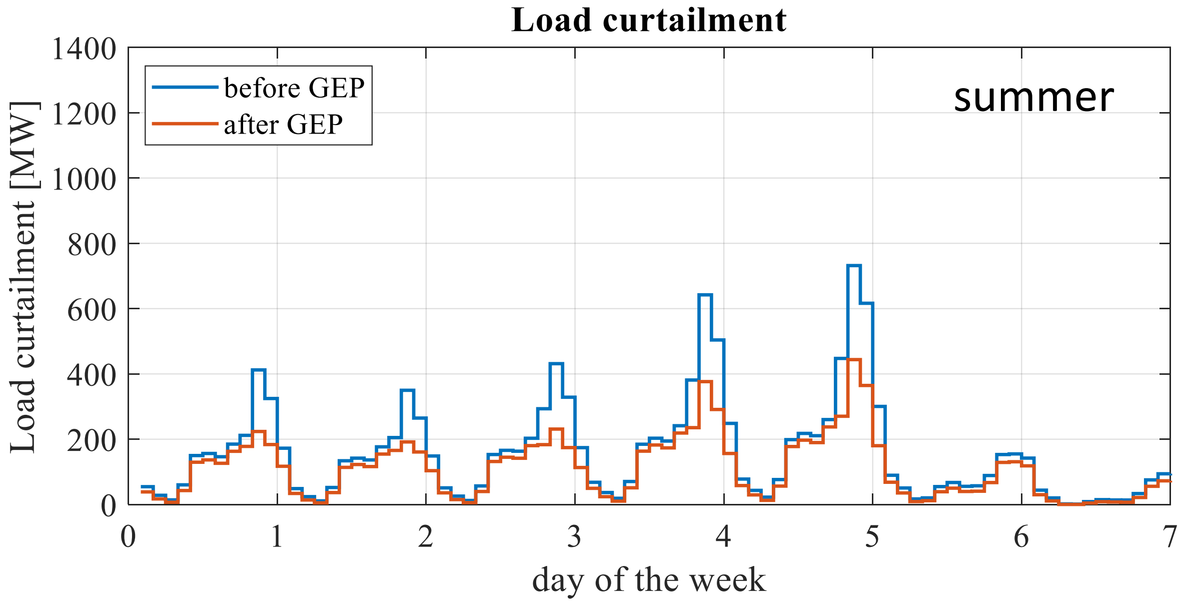
New storage unit

# Results of the planning process

## Grid Expansion Planning (load curtailment) → 2030



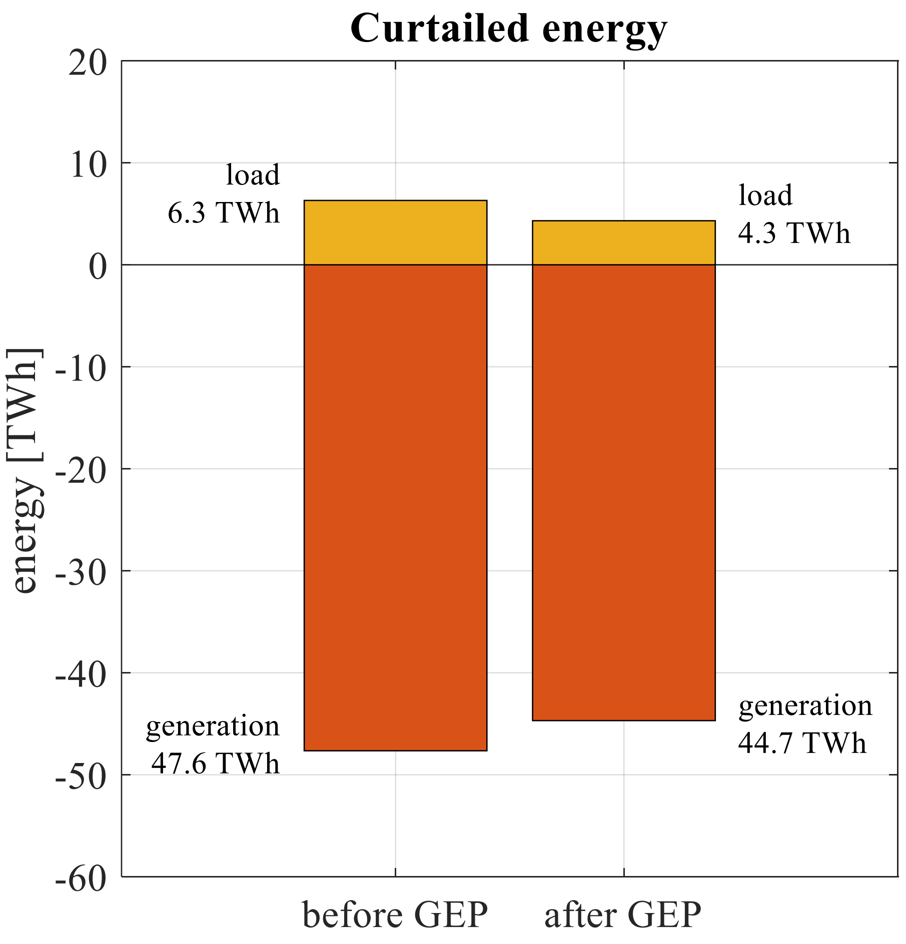



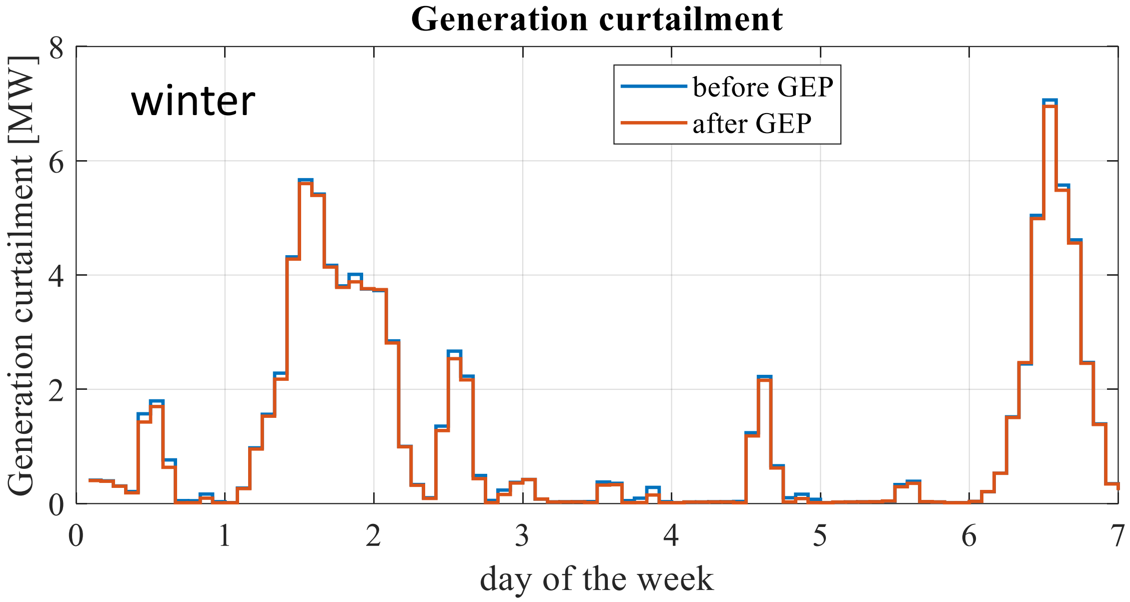



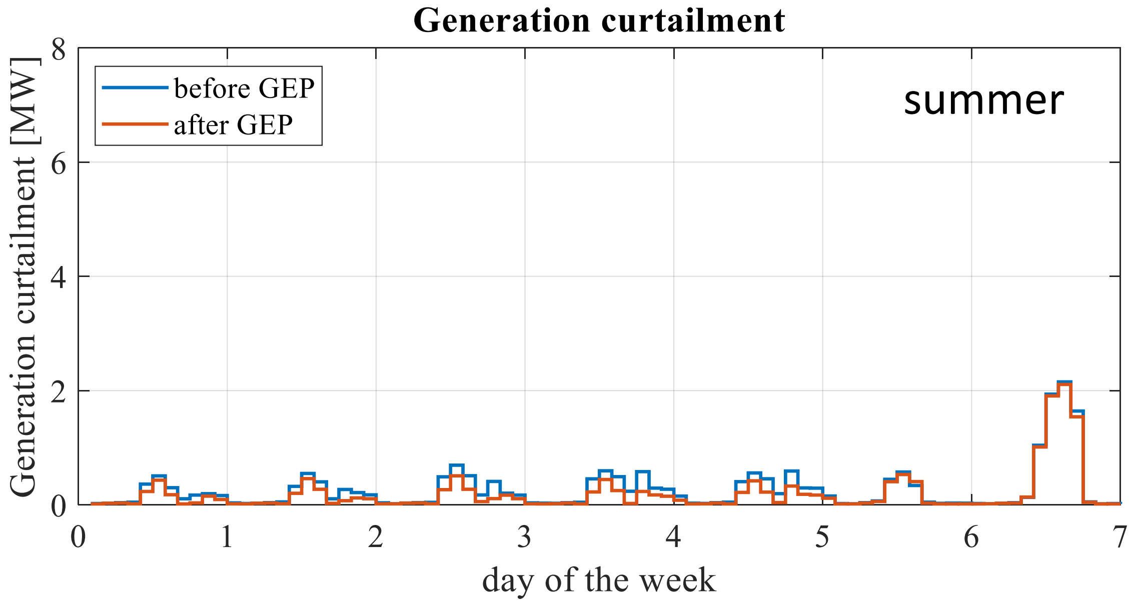

N.B. Simulation results do not reflect an acceptable operating condition of the power system. This is due to the computational power constraints which limit the number of congestions assessed by the tool.

# Results of the planning process

## Grid Expansion Planning (renewables curtailment) → 2030



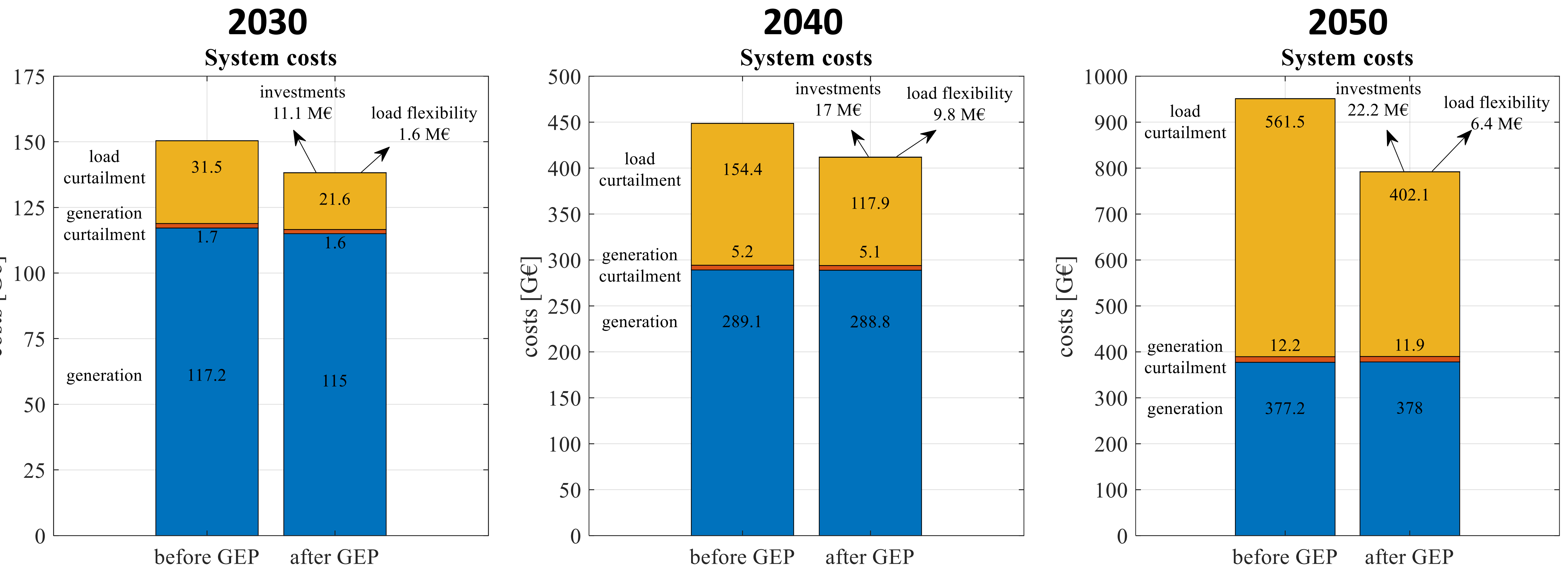




N.B. Simulation results do not reflect an acceptable operating condition of the power system. This is due to the computational power constraints which limit the number of congestions assessed by the tool.

# Results of the planning process

## Results → 2030 + 2040 + 2050




The criticality of load curtailment increased in 2040 and 2050, because of the combination of demand increase and 2030 unsolved congestions. It is evident that the number of candidates plays a fundamental role for both the optimality and the management of load/generation curtailment situations.

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# Role of storage and demand flexibility

## Storage support to grid planning (transmission)

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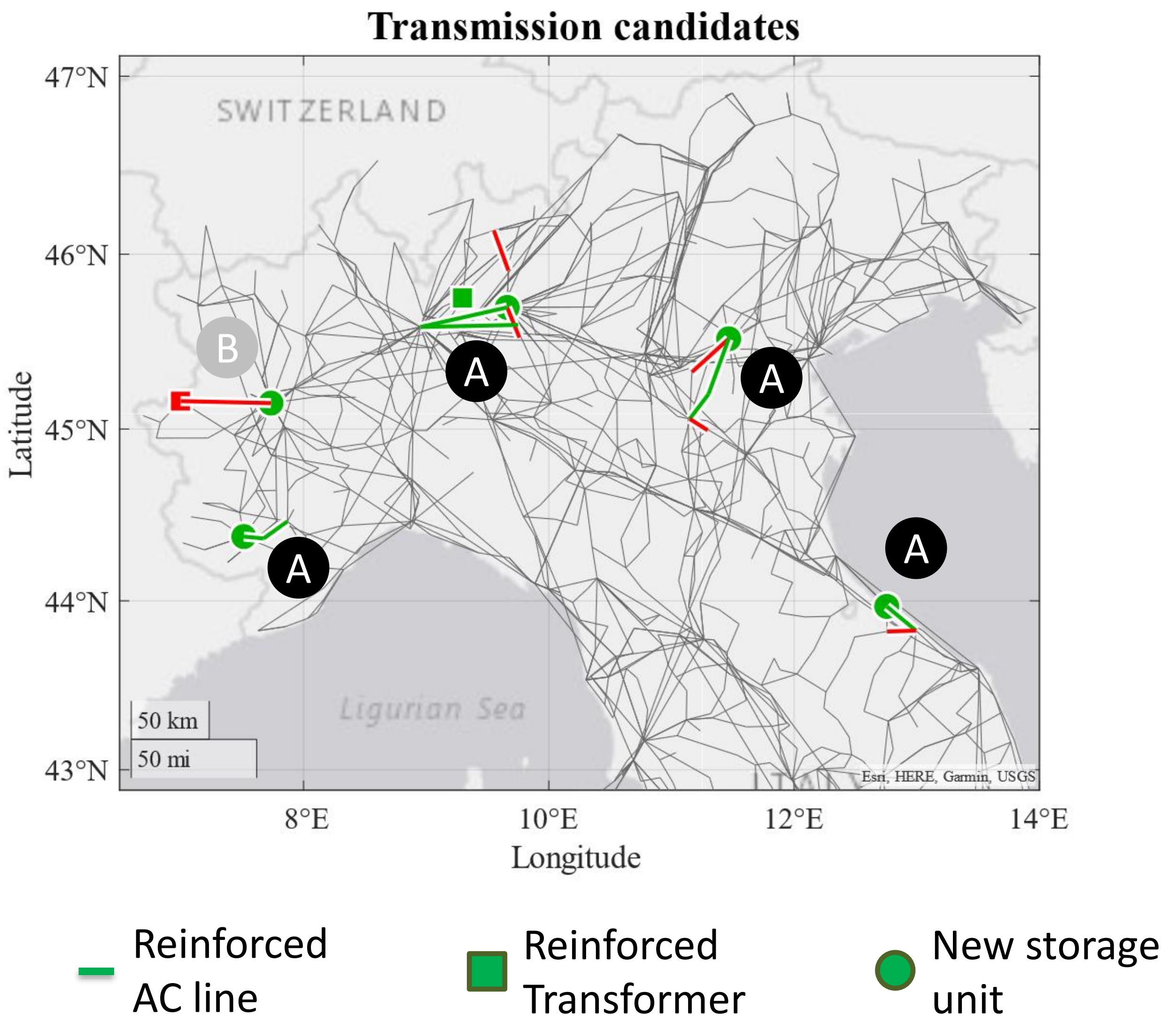
For the most severe congestions expected at transmission level, the preprocessor proposes:

- ❑ **A set of lines and transformer reinforcements** (corridor related to the selected congestion)
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)

**<u>CASE A</u>**

- In most of the cases, storage units are selected together with corridor reinforcement:
  - Line reinforcement solves the persistent overloading and significantly decreases the related congestion severity
  - Storage units are working in synergy with enhanced lines and support the management of periodic (and short-duration) congestions



# Role of storage and demand flexibility

## Storage support to grid planning → CASE A

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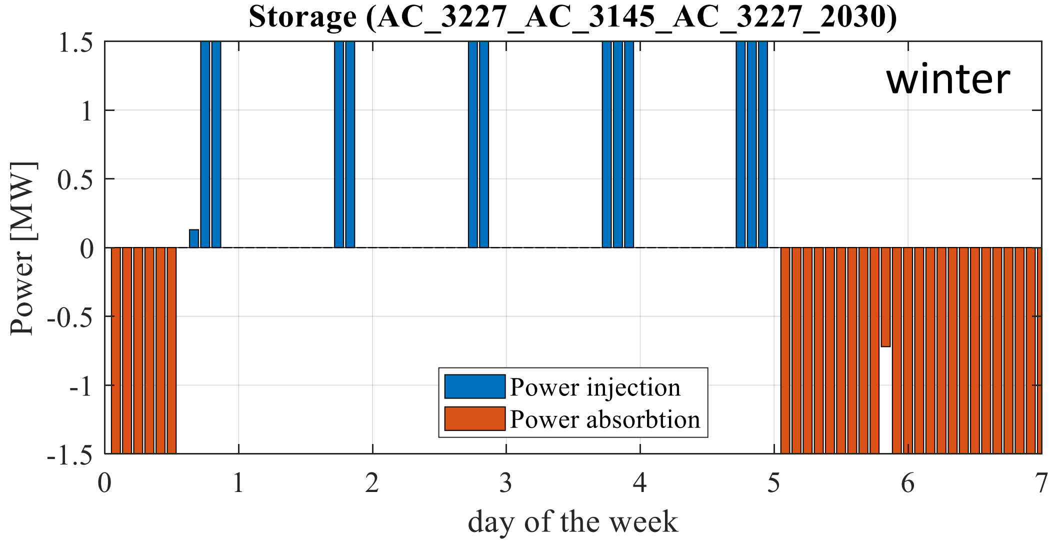


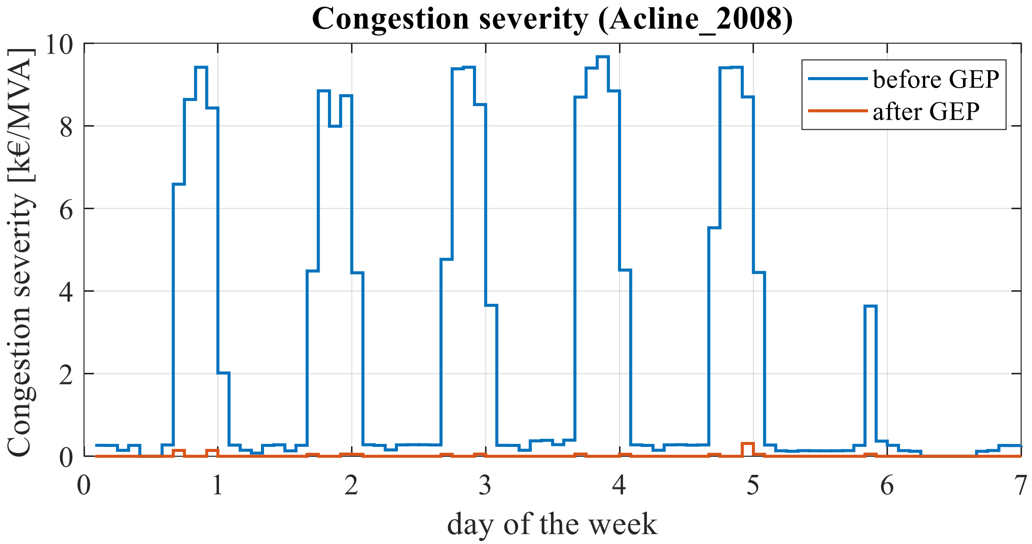


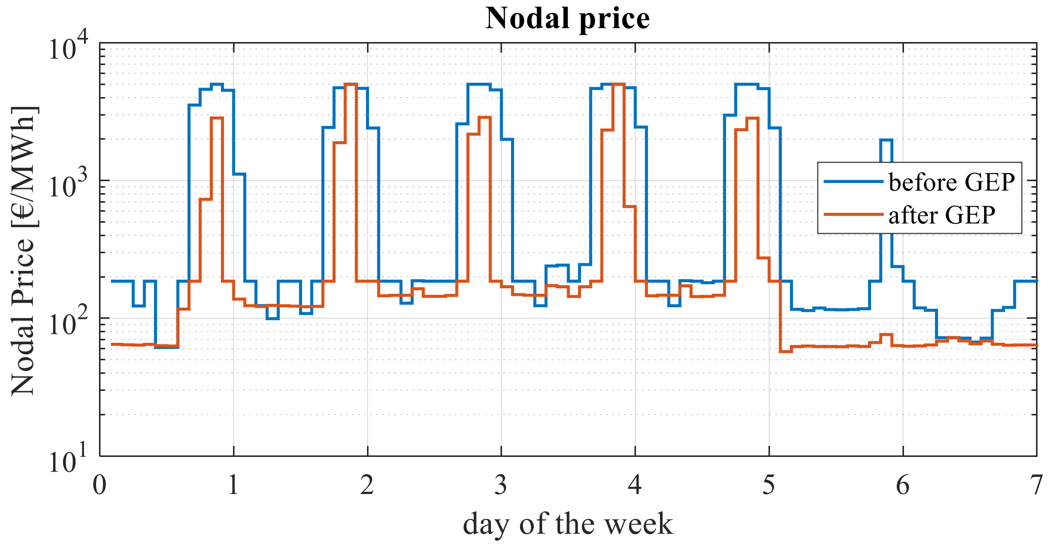


- The congestion severity goes to zero, thanks to the synergy of both line reinforcement and storage (which power contribution matches the time instants of previous congestions)
- Another congestion persists on the grid, and it causes a periodic curtailment of local load (high local price in evening hours)

# Role of storage and demand flexibility

## Storage support to grid planning → CASE A

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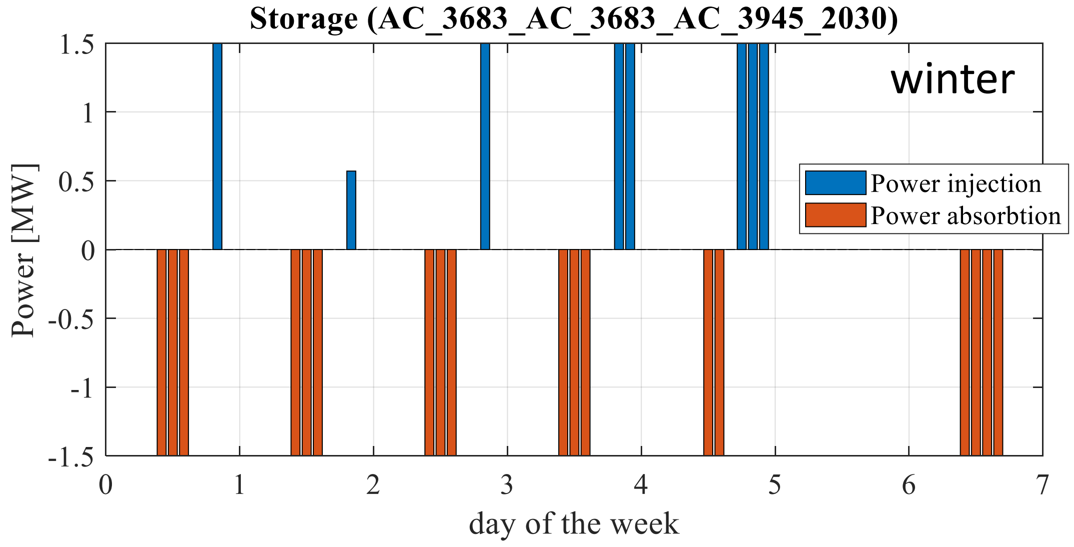
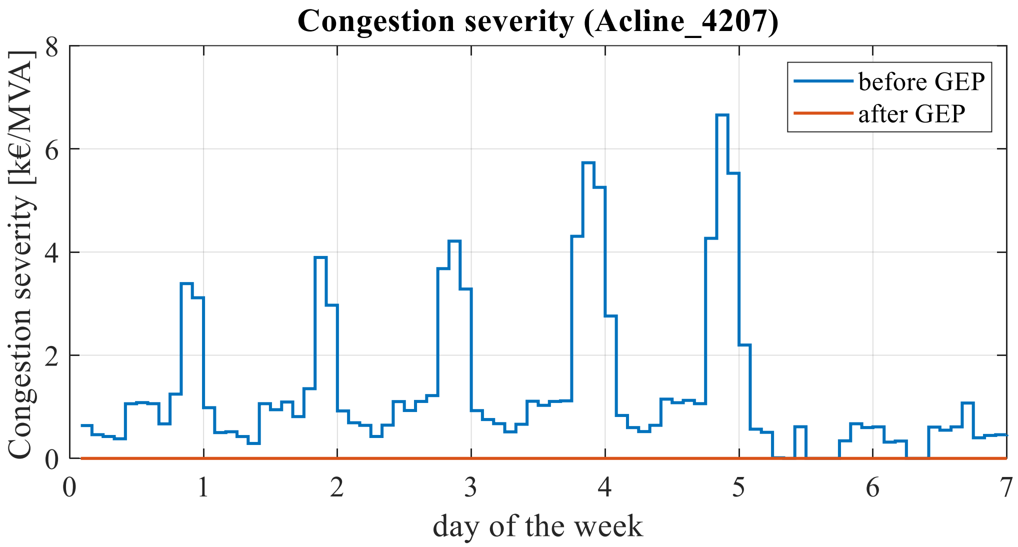
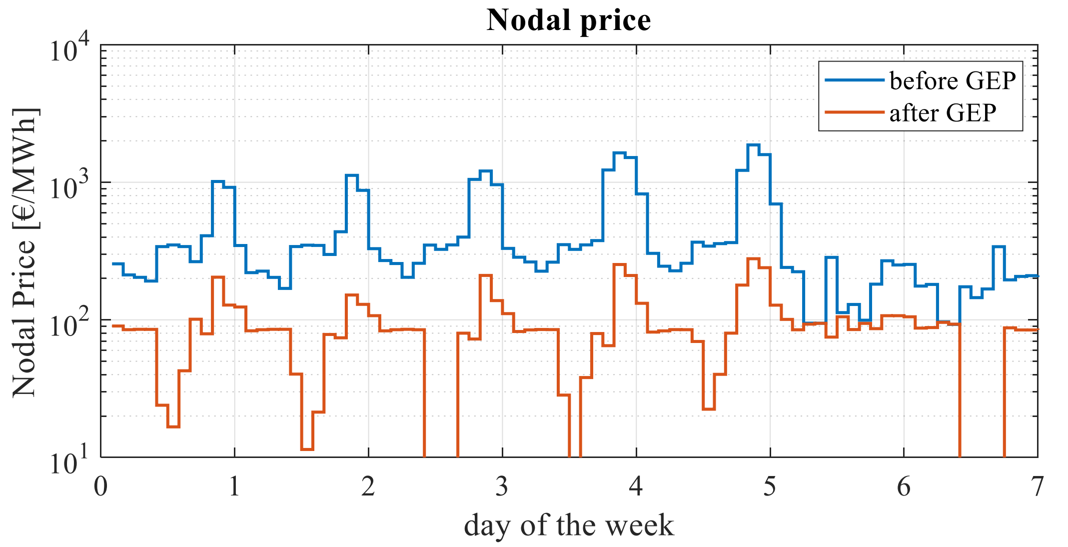



- The congestion severity goes to zero, but this time the main credit is attributed to line reinforcement
- In this case storage is selected by the GEP process in order to perform arbitrage functions
  - It stores energy during photovoltaic peak hours (nodal price=0), while it injects power when the nodal price is higher
  - The revenue of arbitrage is sufficient to justify storage investment

# Role of storage and demand flexibility

## Storage support to grid planning

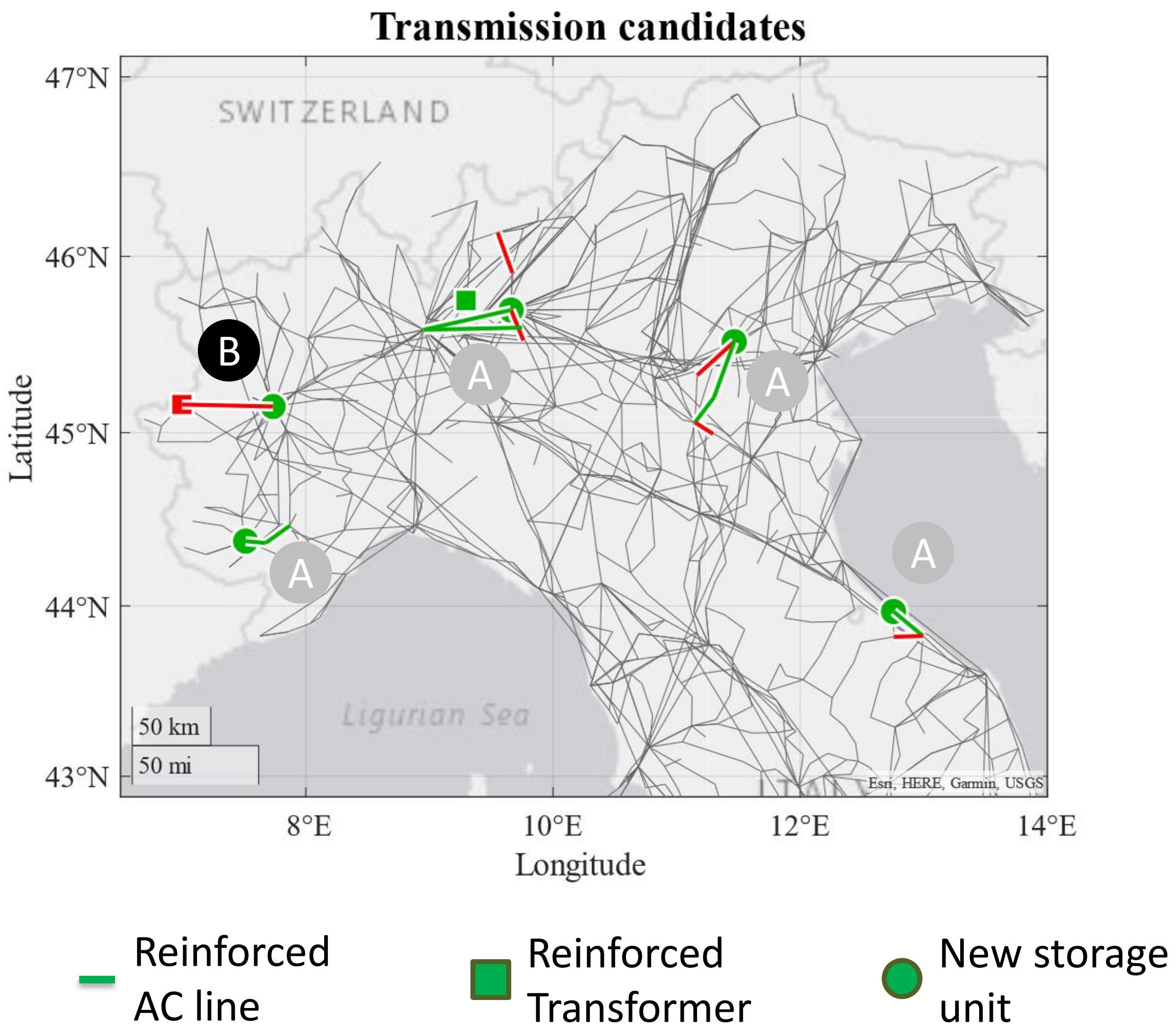
FlexPlan

For the most severe congestions expected at transmission level, the preprocessor proposes:

- ❑ **A set of lines and transformer reinforcements** (corridor related to the selected congestion)
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)

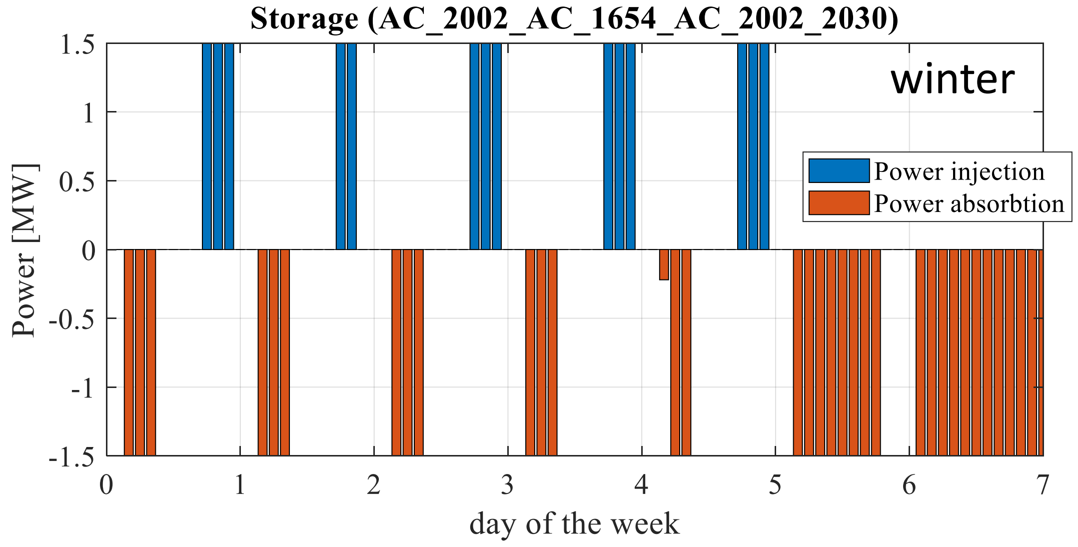
**CASE B**

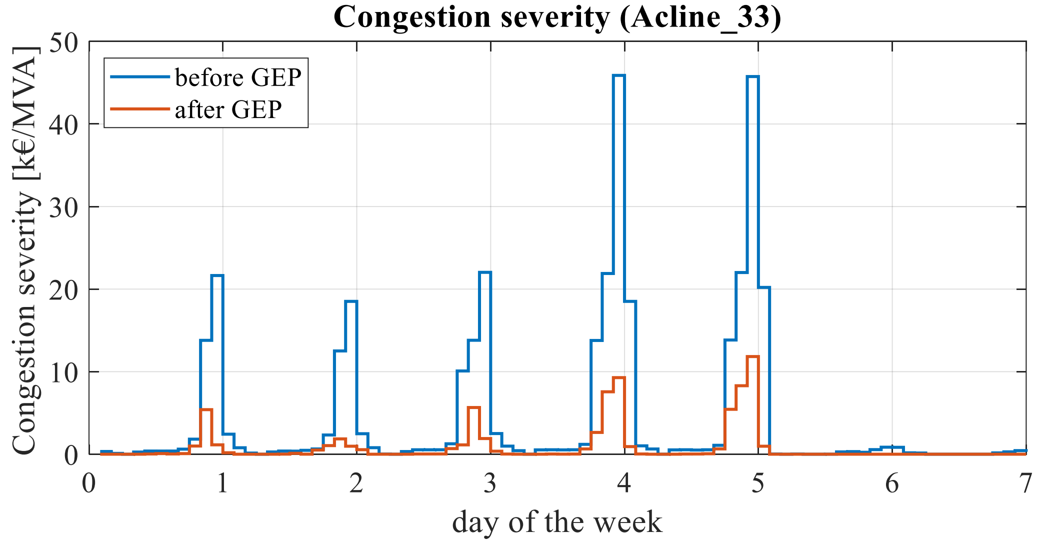
- In one circumstance, a storage unit is selected without the reinforcement of the corresponding corridor
  - In this case, the corridor includes transformer which significantly increases the cost of the conventional grid reinforcement
  - The interested line are congested for a limited number of hours (curtailment of evening load during business days)

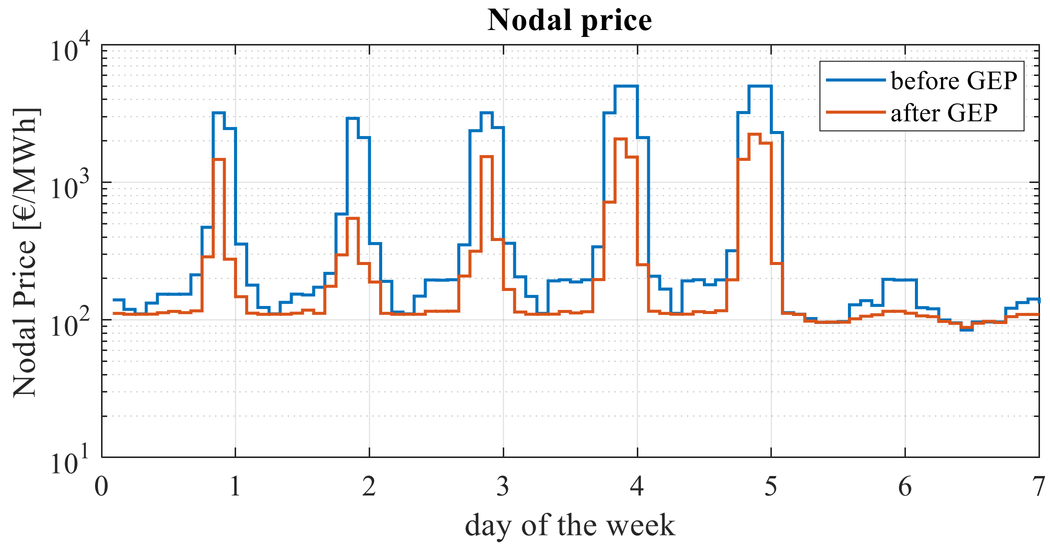


# Role of storage and demand flexibility

## Storage support to grid planning → CASE B



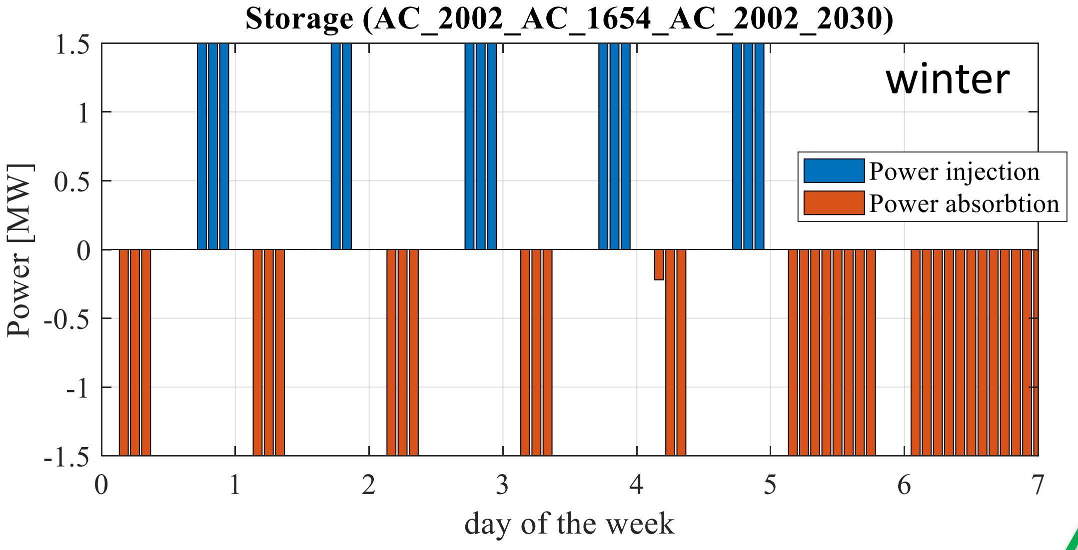



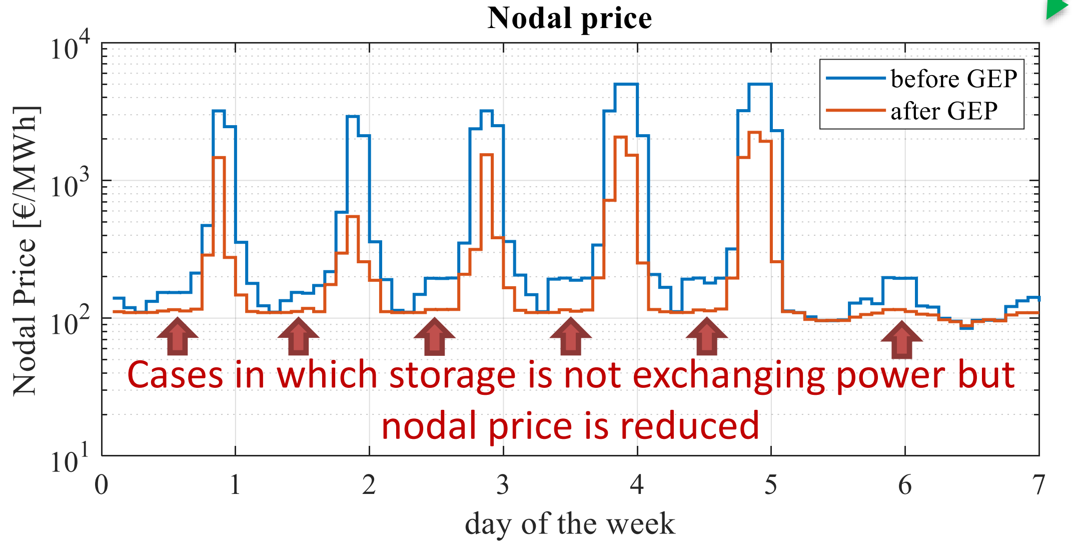




- Nodal price evolution indicates load curtailment during business-day evenings (for a few hours in the evening)
- Storage is selected in order to supply energy to local loads:
  - It reduces the level of congestion of the corresponding corridor
  - The nodal price is still high: its power capacity is not sufficient to entirely supply the local curtailed demand

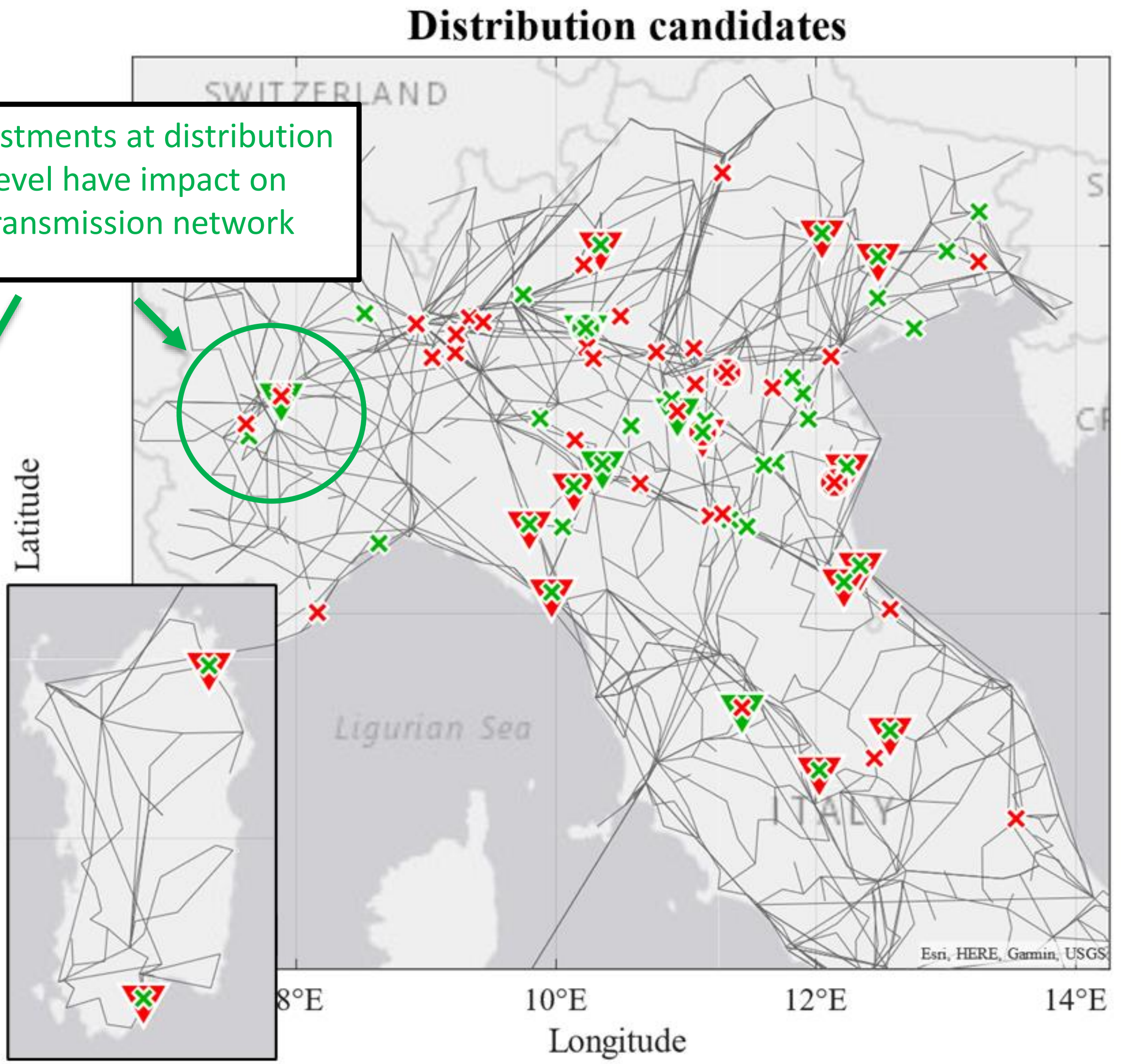
# Role of storage and demand flexibility

## Storage support to grid planning → CASE B




Investments at distribution level have impact on transmission network



# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE A

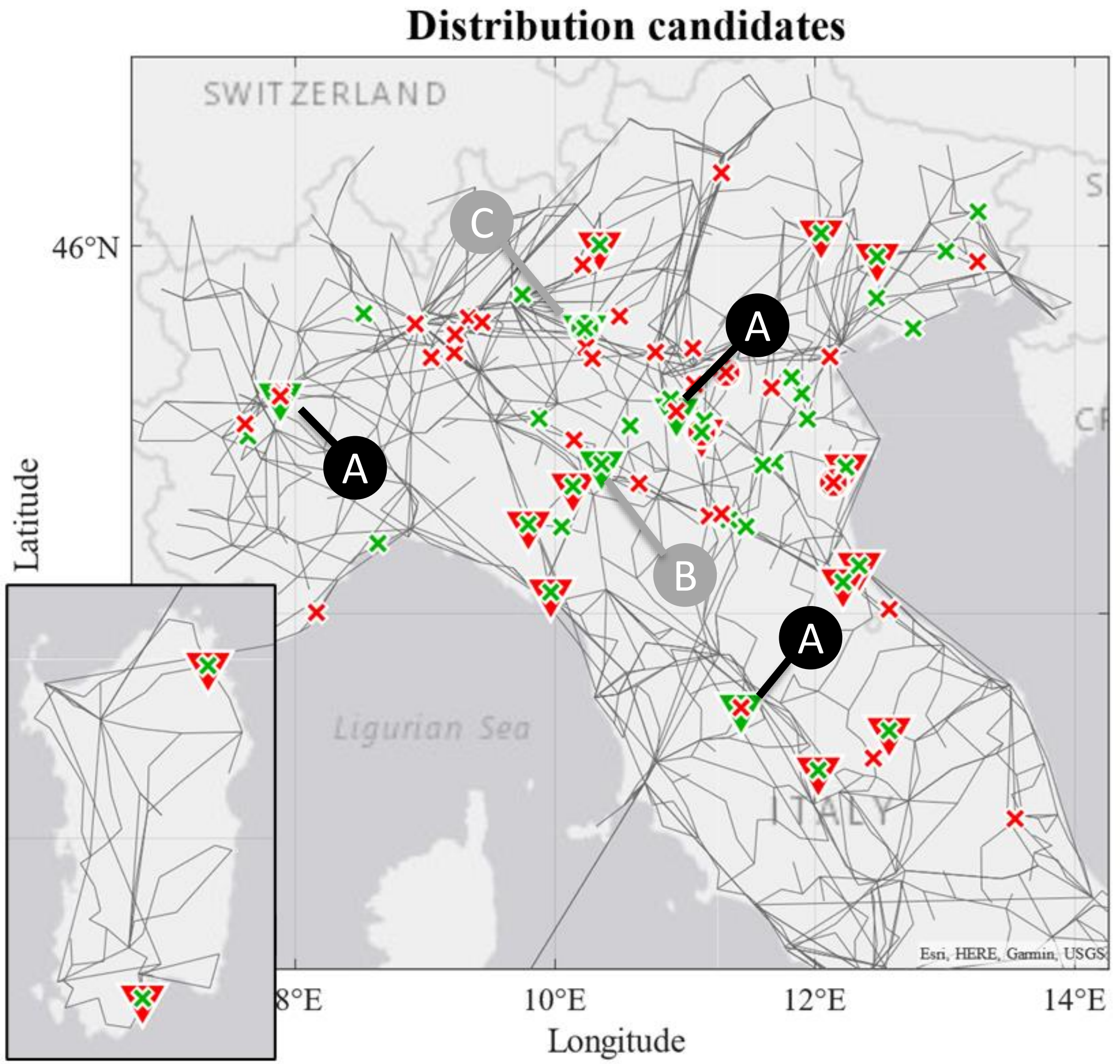
FlexPlan

For the most severe congestions expected at distribution level, the preprocessor proposes:

- ❑ **A set of lines and transformer reinforcements** (corridor related to the selected congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)

**CASE A**

- Both line reinforcement and load flexibilization are proposed as planning candidates
- Only load flexibilization is accepted




Reinforced AC line

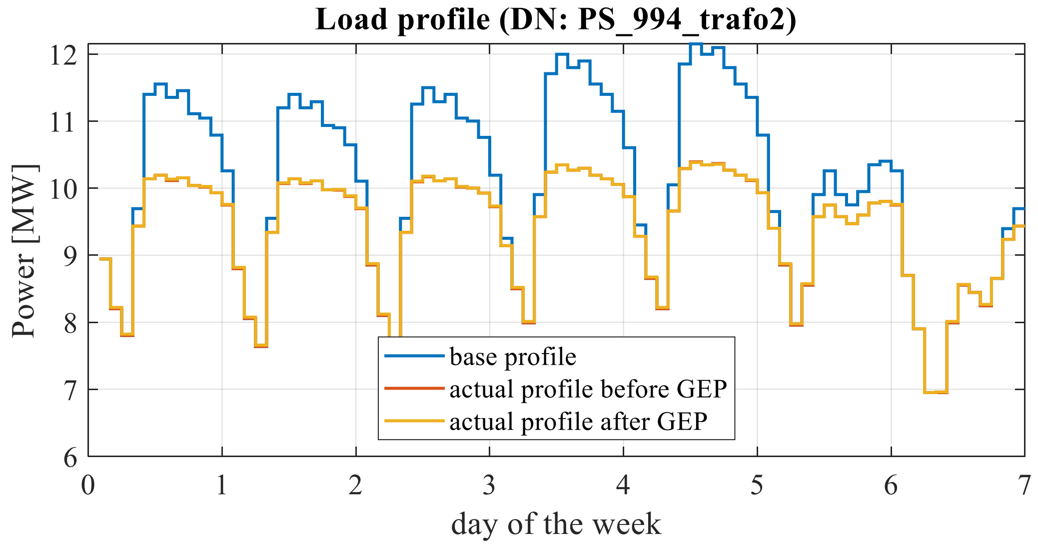
Flexibilization of existing load

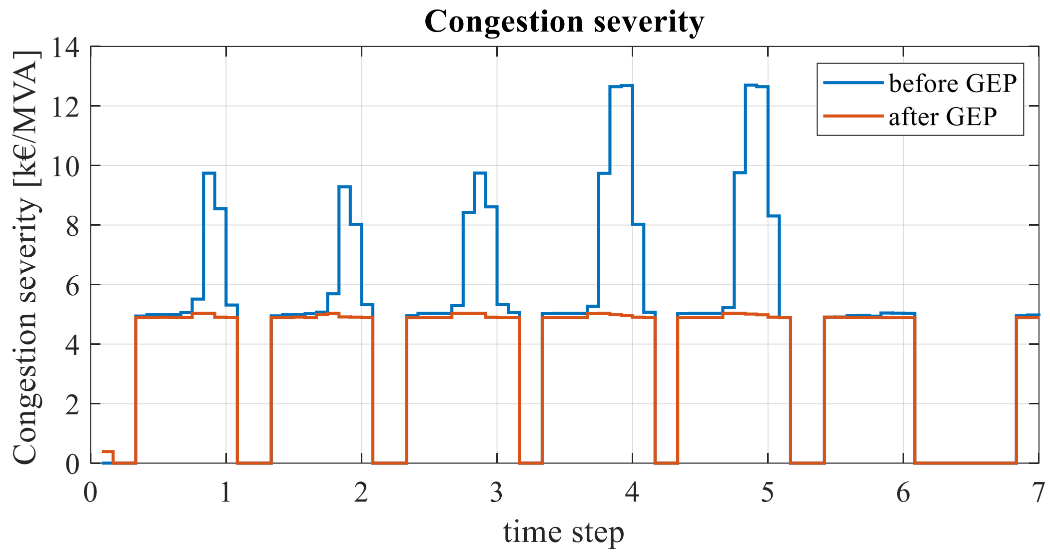
New storage unit

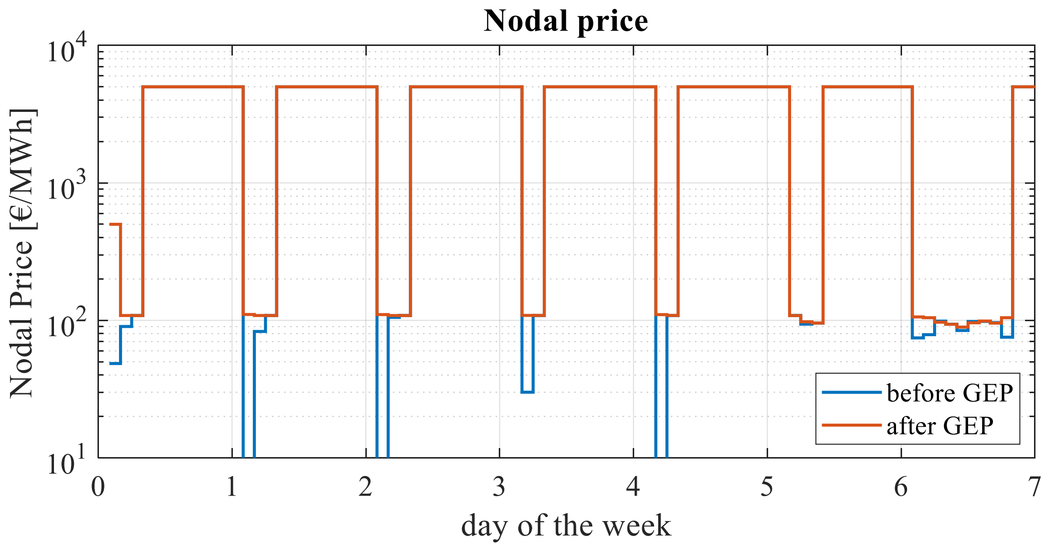
# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE A

FlexPlan



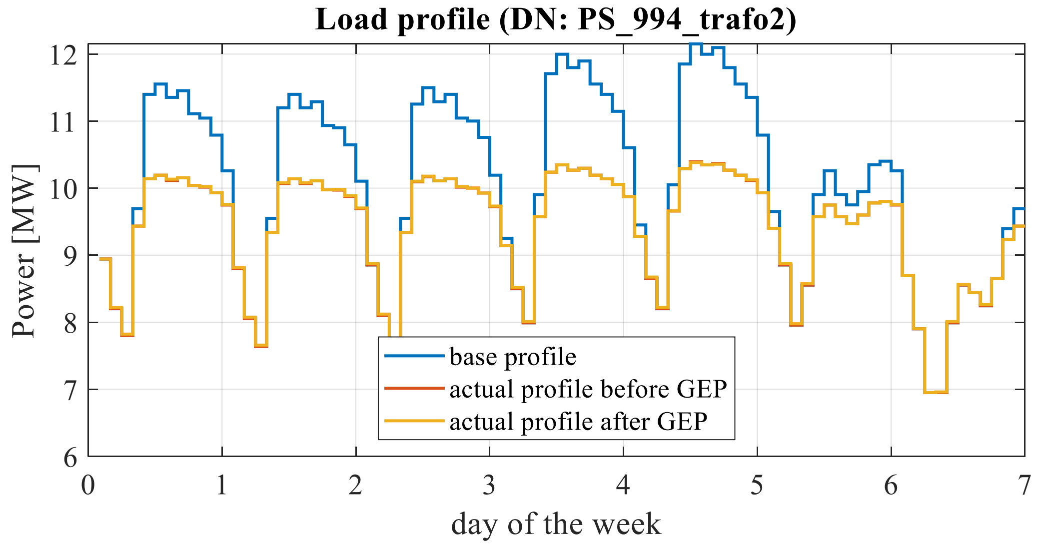



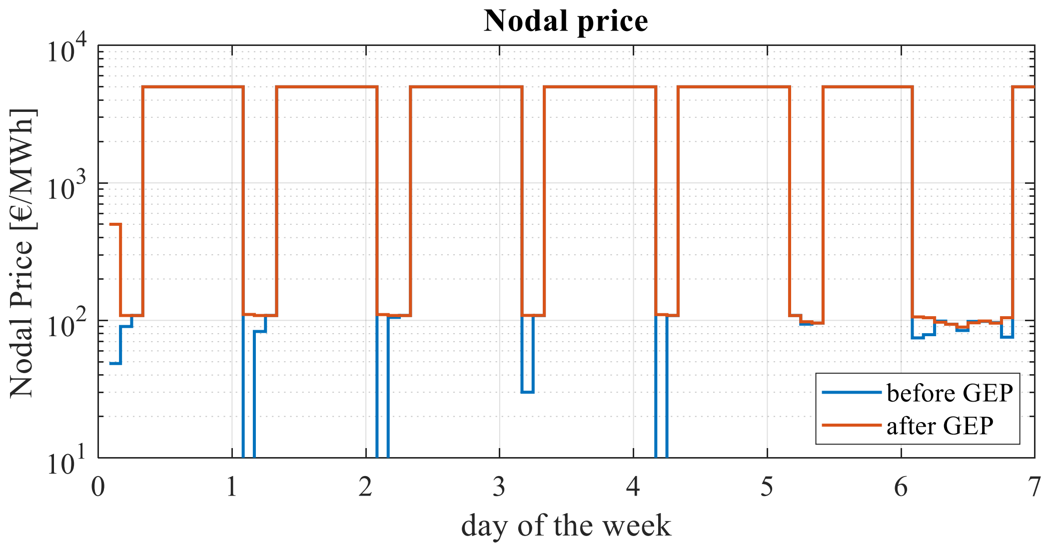



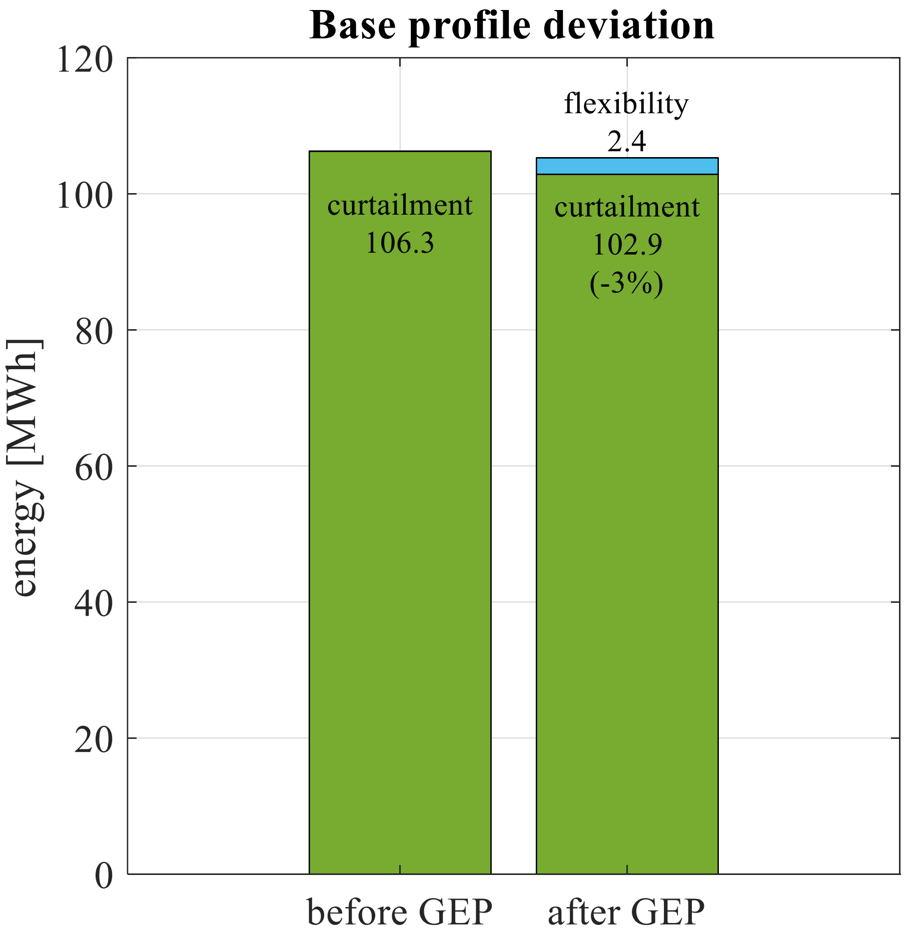

- The evolution of nodal price indicates that flexible load is not sufficient to clear the existing congestion and load curtailment persists
- Contribution of load flexibility:
  - It reduces the nodal price during the early morning, since it optimizes the consumption of local renewable energy sources
  - It contributes to the reduction of congestion severity during evening hours

# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE A



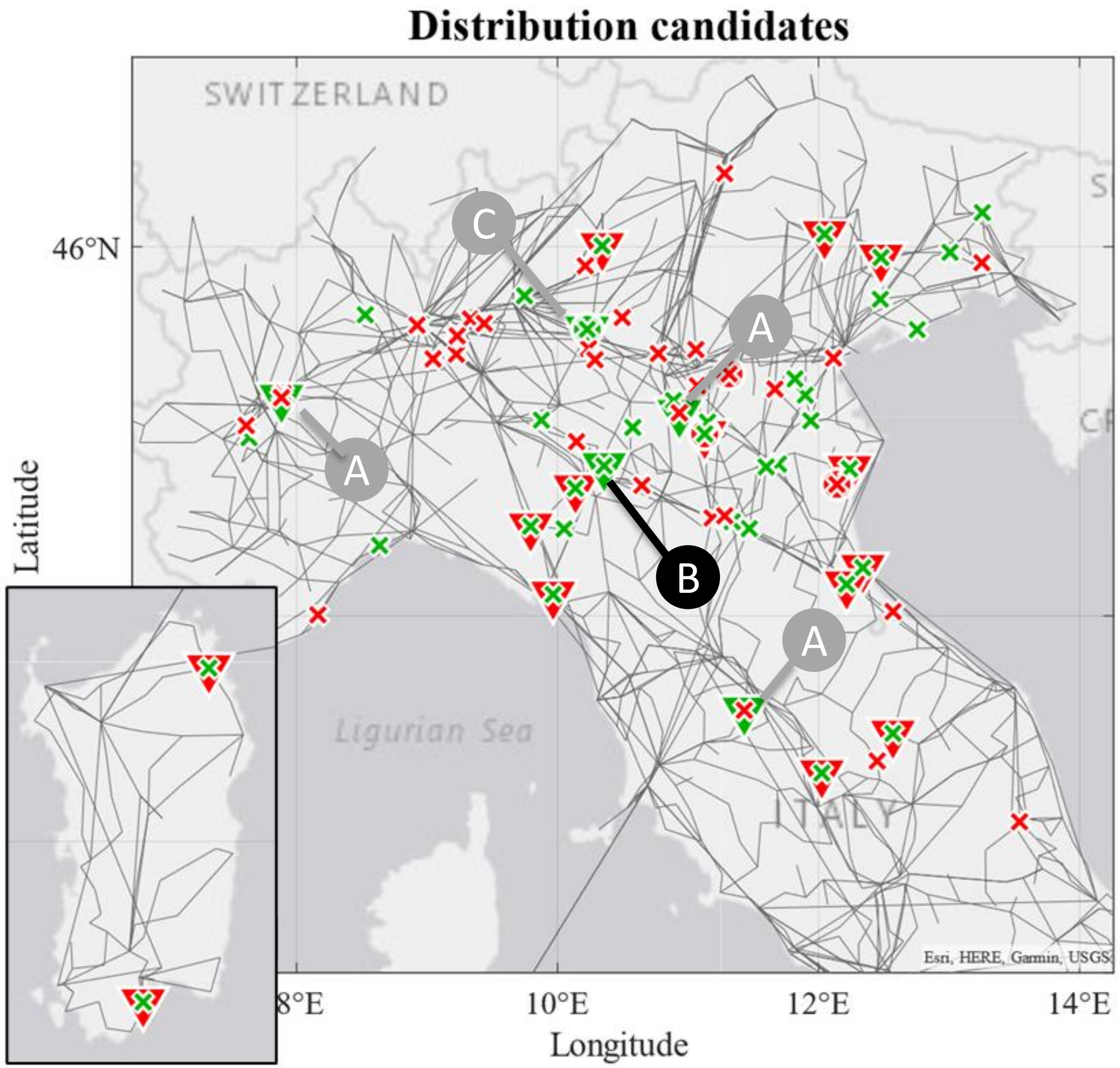
# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution)

FlexPlan

For the most severe congestions expected at distribution level, the preprocessor proposes:

- ❑ **A set of lines and transformer reinforcements** (corridor related to the selected congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)




**CASE B**

- Both line reinforcement and load flexibilization are proposed as planning candidates
- Both the options are selected

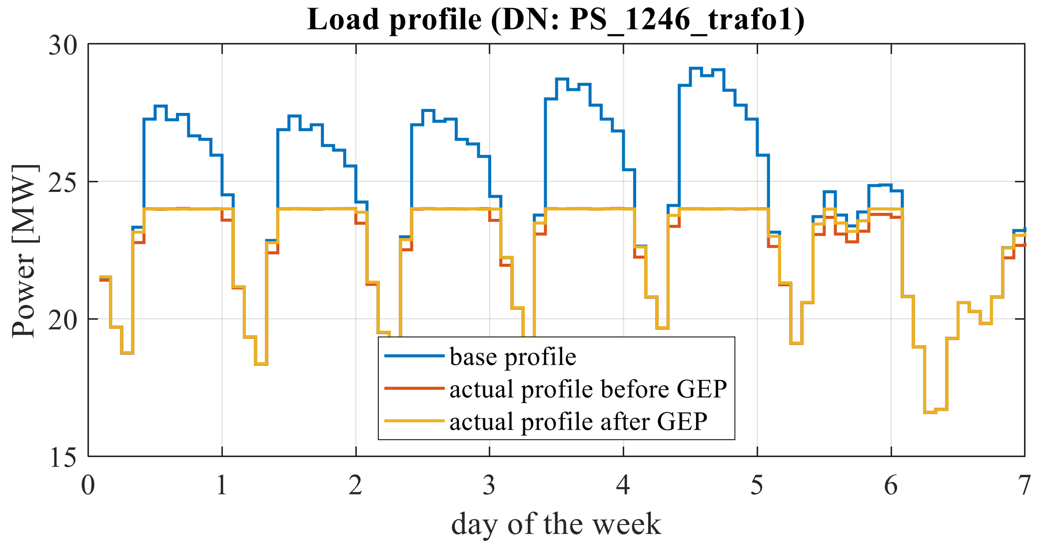
Reinforced AC line

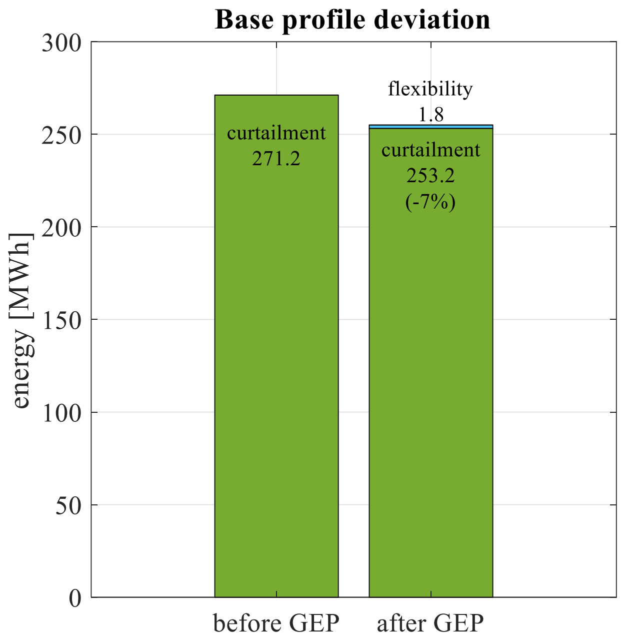
Flexibilization of existing load

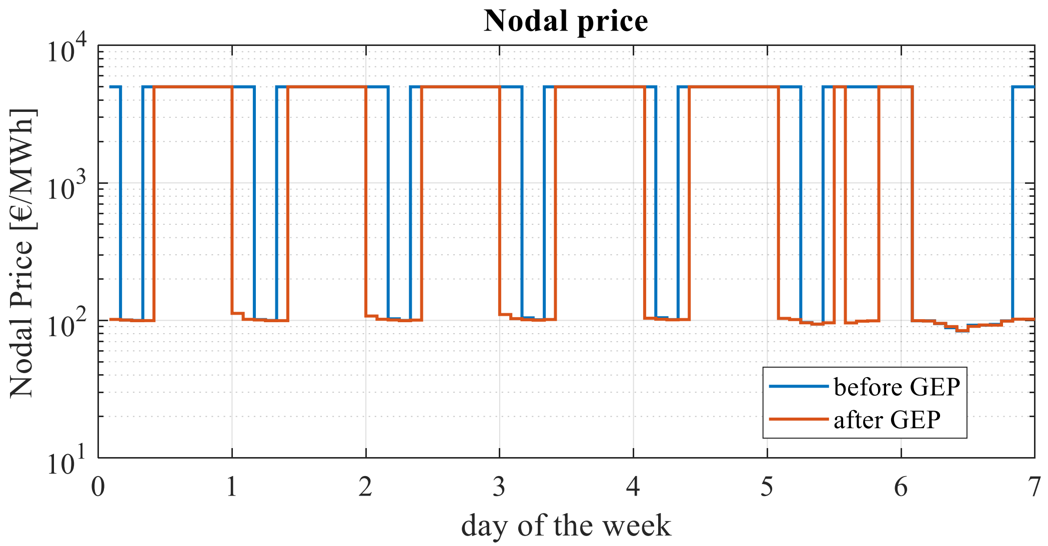
New storage unit

# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE B




- The reinforcement of the congested line is not sufficient to avoid load curtailment for the selected network (other congestions persist on it)
- In this case, the most evident contribution is attributed to the line reinforcement:
  - It clears the congestion in during the early morning
  - Load flexibility marginally reduces the nodal price during the non-congestion time steps

# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution)

FlexPlan

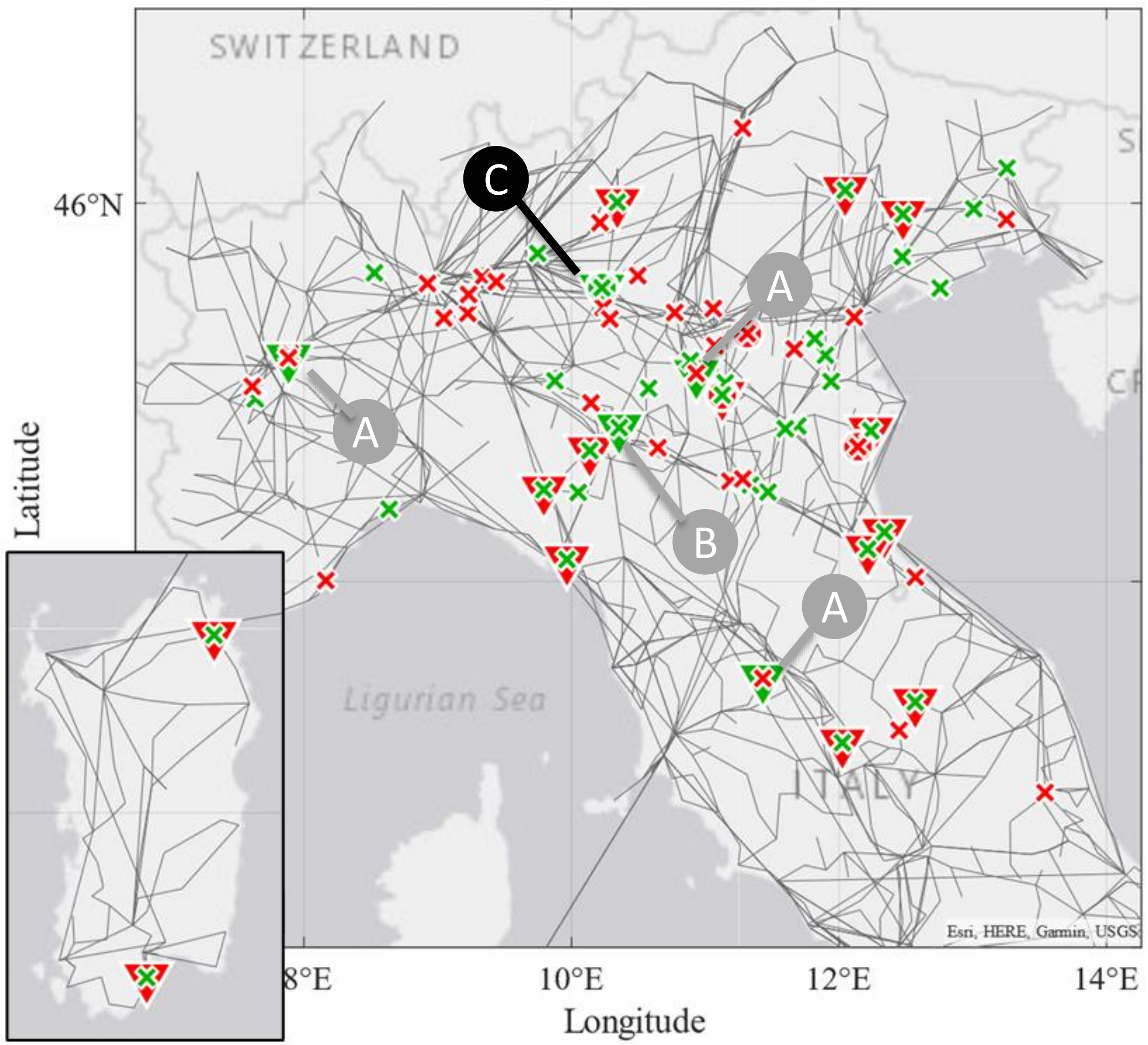
For the most severe congestions expected at distribution level, the preprocessor proposes:

- ❑ **A set of lines and transformer reinforcements** (corridor related to the selected congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)

**CASE C**

- Load flexibilization, storage and line reinforcement have been proposed as planning candidates
- All the options have been activated

**Distribution candidates**



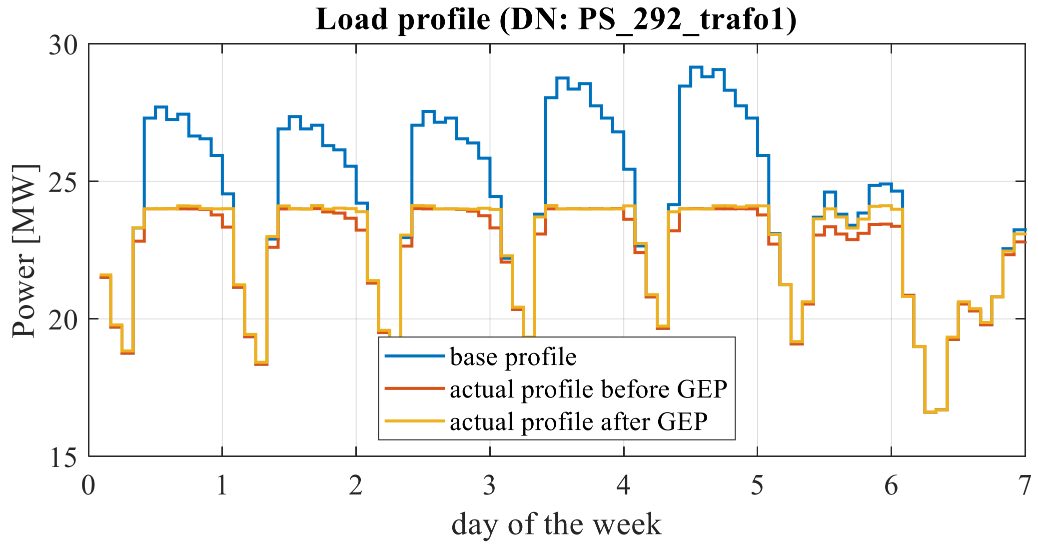

Reinforced AC line

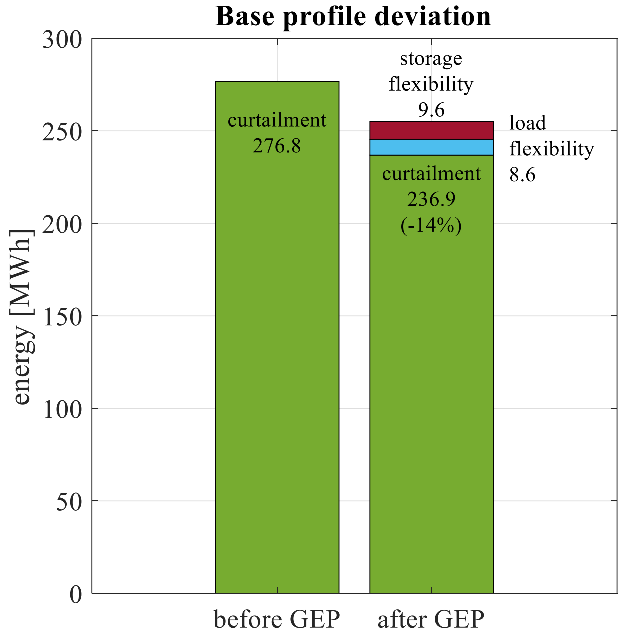
Flexibilization of existing load

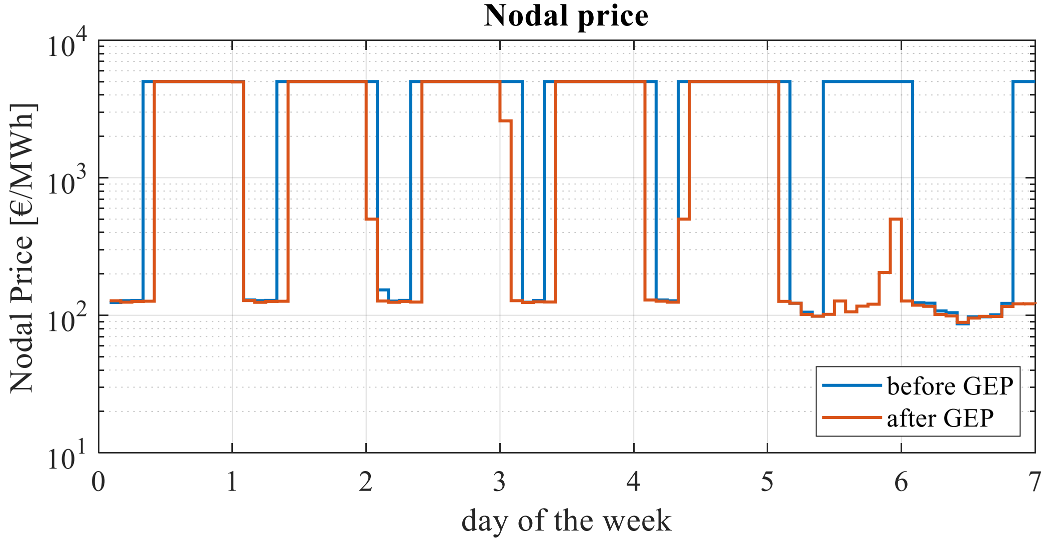
New storage unit

# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE C




- In this case, the selected candidates (line reinforcement, storage and load flexibilization) support the reduction of load curtailment (even though network congestions are not entirely solved)
  - The largest benefits are attributable to line reinforcement
  - Flexible load and storage equally contribute to the reduction of load curtailment

# Role of storage and demand flexibility

## Flexibility support to grid planning (distribution) → CASE C

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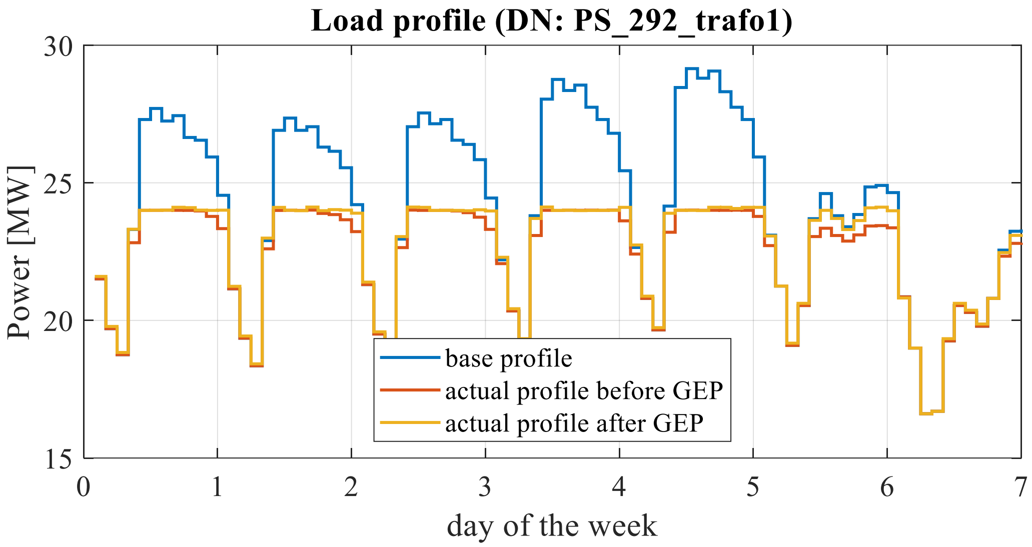


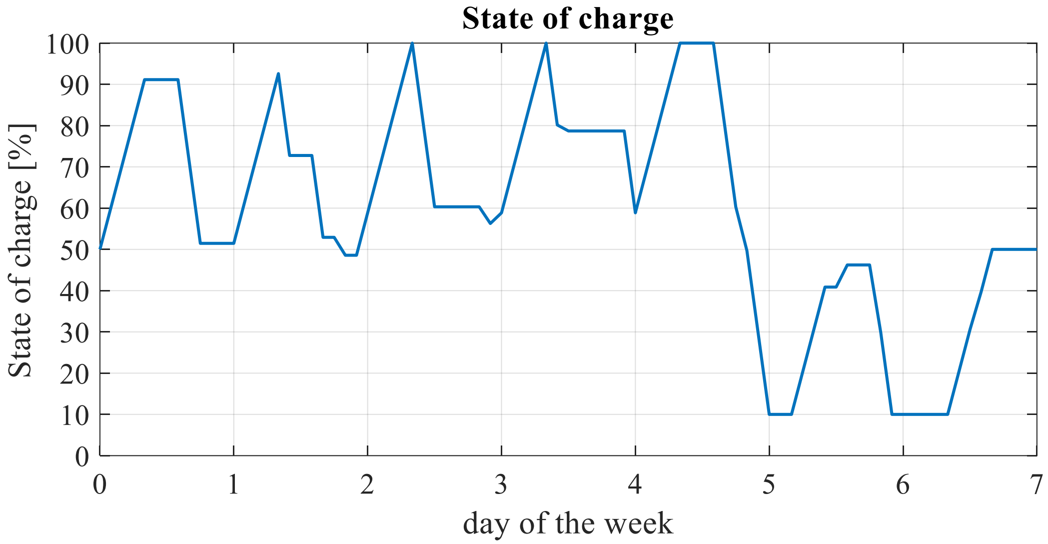


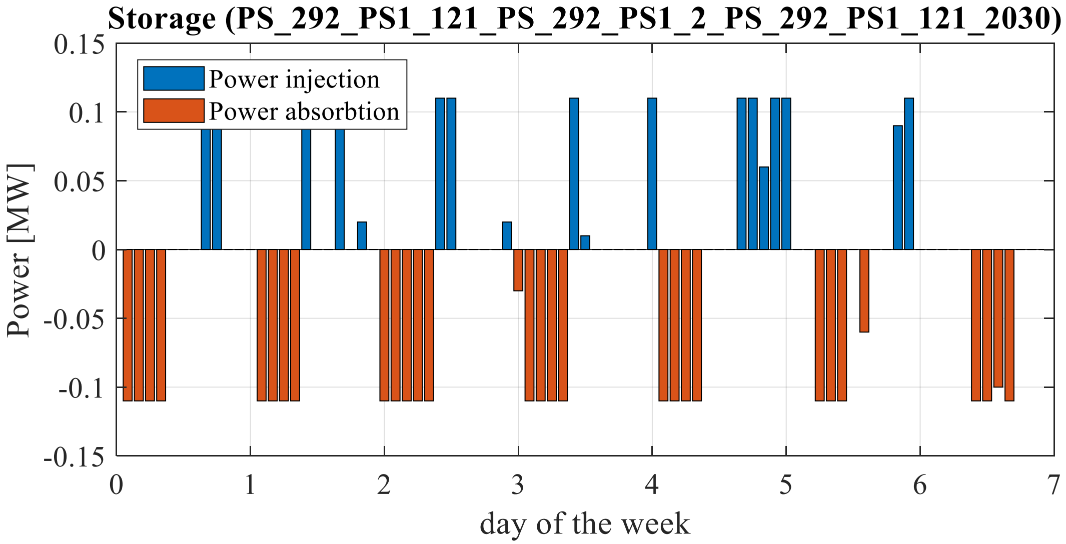


- Storage usage is proportional to the severity of the congestion
  - It injects energy mostly during the second half of Friday, when load curtailment is maximum
- The contribution of storage is limited by both the power and energy capacity of the selected device

# Thank you…

Marco Rossi

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# FlexPlan

[FlexPlan-Project.eu](FlexPlan-Project.eu)

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