FlexPlan

Italian RC Workshop| 25th January 2023

The FlexPlan project: motivations, consortium and methodology

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Agenda

- Critical aspects of the present grid planning methodologies
- The FlexPlan project: aim, partnership, activities overview
- The Grid Expansion Planning tool: modelling aspects
- Monte Carlo approach and Benders' decomposition
- T&D decomposition
- The pre-processor
- Interaction between pre-processor and planning tool
- Grid Expansion Planning tool and Open Access libraries
- The Final Project Workshop in Brussels

Critical aspects of the present grid planning methodologies *FlexPlan*

- The new context (high-speed deployment of RES in electric T&D grids, increased penetration of DER in distribution grids, consequent strong need for flexibility in the electric grids) should bring grid planners to rethink some foundations of the grid planning methodologies which are applied nowadays.

Critical drivers	Problems in coping with it in present grid planning
Massive penetration of RES in T&D grids also in consequence of ambitious decarbonization targets (and, lately, the need to increase Europe independency from fossil fuels purchase) **and public opposition to deploy new lines** (resulting in long times for getting building permission)	• **need to co-evaluate a high number of candidates** due to ever-changing RES scenarios: limits in the "with and without planning approach". • **the deployment of new lines could not be economically efficient if we need to compensate congestion created by RES variability** maybe lasting just few hours: traditional grid planning disregards the role of flexibility! • **storage and DSM should become full fledged planning candidates**. • need for a new grid planning approach considering **multi-scenarios in a probabilistic way** to incorporate the effect of different climate years. • need to find a **quantitative methodology to internalize environmental externalities in an objective way** (i.e. quantitatively) to compare costs/benefits of RES wrt conventional plants generation.
New scenarios need to look at short and long term (2050 or even beyond) in order to gather a complete overview on the decarbonization path of the European system	• **traditional grid planning analyses one year a time** (e.g. first expansion at 2030, then 2040 then 2050). This can bring to a sub-optimal strategy.
Distribution grids are becoming active and able to deliver power and services to transmission grids	• **distribution grid planning based on fit-and-forget methodology** i.e. on sizing the grid for a "worst case" disregarding actual flows and real time grid bottlenecks. • **lack of integration between T&D grids planning**.

The FlexPlan project

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- **Start date: 01.10.2019**
- **End date: 30.09.2022**

… aims at establishing **a new grid planning methodology** considering the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to building new grid elements.

FlexPlan: partnership

- **Research Partners:**
  - **RSE**, Italy (Project Coordinator, WP7 and WP8 leader)
  - **EKC**, Serbia
  - **KU-Leuven**, Belgium (WP1 leader)
  - **N-SIDE**, Belgium (WP3 leader)
  - **R&D NESTER** Portugal (WP5 leader)
  - **SINTEF**, Norway (WP6 leader)
  - **TECNALIA**, Spain (WP2 leader)
  - **TU-Dortmund**, Germany (WP4 leader)
  - **VITO**, Belgium

- **Transmission System Operators:**
  - **TERNA**, Italy
    - **Terna Rete Italia** as Linked third Party
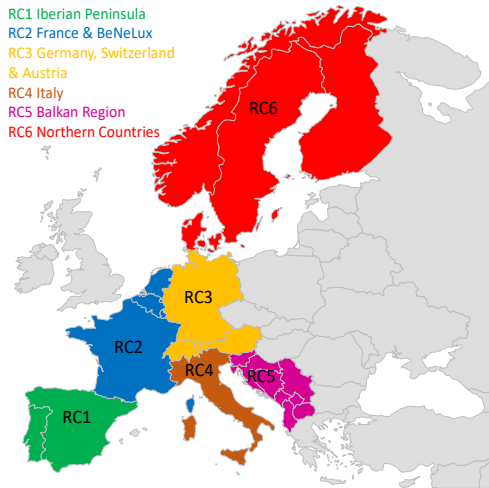 - **REN**, Portugal
  - **ELES**, Slovenia

- **Distribution System Operators**
  - **ENEL** Global Infrastructure and Networks
    - **e-distribuzione** as Linked third Party

What FlexPlan will achieve

1 – New planning methodology - Creation of a **new tool for optimizing T&D grid planning**, considering the **placement of flexibility elements** located both in transmission and distribution networks **as an alternative to traditional grid planning**: in particular, storage, PEV, demand response)


RC1 Iberian Peninsula
RC2 France & BeNeLux
RC3 Germany, Switzerland & Austria
RC4 Italy
RC5 Balkan Region
RC6 Northern Countries

2 – Scenario analysis 2030-40-50 - New methodology applied to analyse **six regional grid planning scenarios at 2030-2040-2050.** A **pan-European scenario** will deliver border conditions to initialize in a coherent way the 6 regional cases.

3 – Regulatory guidelines – FlexPlan goal is to provide:
- an optimized planning methodology for the future usage of TSOs and DSOs
- indications on the potential role of flexibility and storage as a support of T&D planning
- guidelines for NRA for the adoption of opportune regulation.

The FlexPlan approach: a simple example
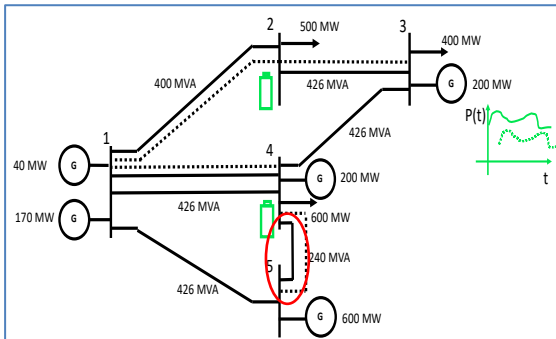
Power transfer capacity of line 4 - 5 limited to 240 MVA, the generation resources connected to bus 5 cannot be utilized to fully supply the demand on bus 3. Investments are needed.

Candidates: four lines (dashed), two storage systems (in green) one flexible demand (in green).
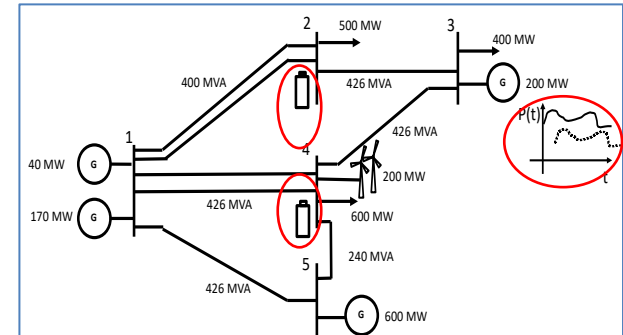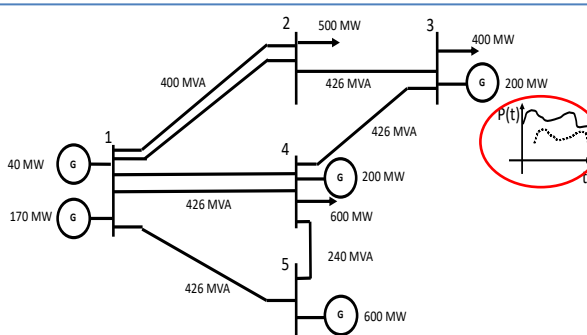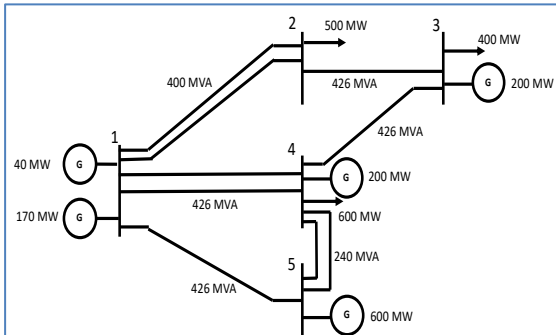
Solution 1 - Classic transmission expansion planning (transmission lines), by designing the system for peak load conditions. If peak load conditions only occur for a limited number of hours this is not economically optimal.

Solution 2 – Omitting investments into line 4-5, as the existing line is sufficient to supply the demand for most of the time, and activate demand flexibility (shifting and/or reduction) whenever needed.

Solution 3 - Conventional generators have been replaced by wind farms, then storage could allow to supply demand in hours of low wind generation and high demand.

The new planning tool

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Pre-processor

Candidate grid investments and flexibility options

Generation and demand time series for 2030, 2040, 2050

T & D grid data based on ENTSO –e TYNDP

Quantify landscape impact costs

Quantify emission and air quality related costs

Optimization model

Objective: Maximum social welfare consisting of investment costs, operational costs, environmental impact, system security impact, benefits of storage and flexibility

Decision variables: Investment decision (binary), generator dispatch, flexibility activation, storage usage

Constraints: T&D grid constraints, T&D security constraints, flexibility characteristics, storage constraints

- Best planning strategy with a limited number of expansion options (mixed-integer, sequential OPF)

- T&D integrated planning

- Embedded environmental analysis (air quality, carbon footprint, landscape constraints)

- Simultaneous mid- and long-term planning calculation over three grid years: 2030-2040-2050

- Probabilistic OPF using 35 climate year variants (RES and load time series) reduced to 2 variants of 4 yearly weeks (one per season) by using clustering-based scenario reduction techniques

- Full incorporation of CBA criteria into the target function

- Probabilistic elements (instead of N-1 security criterion)

- Numerical *ad hoc* decomposition techniques to reduce calculation efforts (Benders, T&D)
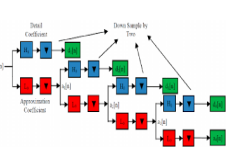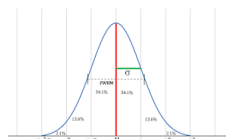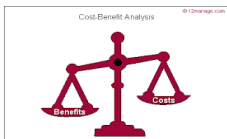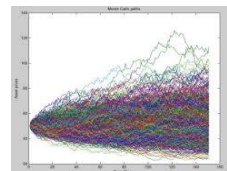
The new planning tool: optimization target function

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y = 2030, 2040, 2050

Operational costs, of existing generation and load including air quality impact and CO_2 emissions impact of conventional power plants

Contingencies costs, as the product of curtailed load and value of lost load weighted over a set of contingencies c, using contingency probabilities

$$min \sum_y f_y^{d,o} \left\{ \sum_t \left[\sum_j (C_{y,t,j}) + \sum_j \alpha_{y,j}(C_{y,t,j}) + \Delta t \sum_{c,j} \widetilde{U}_{y,t,c} C_{y,t,j}^{voll} \Delta P_{y,t,j,c} \right] \right. \left. + f_y^{d,i} \sum_j \alpha_{y,j} I_{y,j} \right\} - \sum_j f_{j,y_{end}}^{d,i} \alpha_{y,j} I_{y,j}^{res}$$

Operational costs of new investments

Investment costs, including carbon footprint (apart conventional generation) and landscape impact costs

Residual Investment value, related to investments with expected life exceeding the simulation horizon

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Modeling of environmental factors
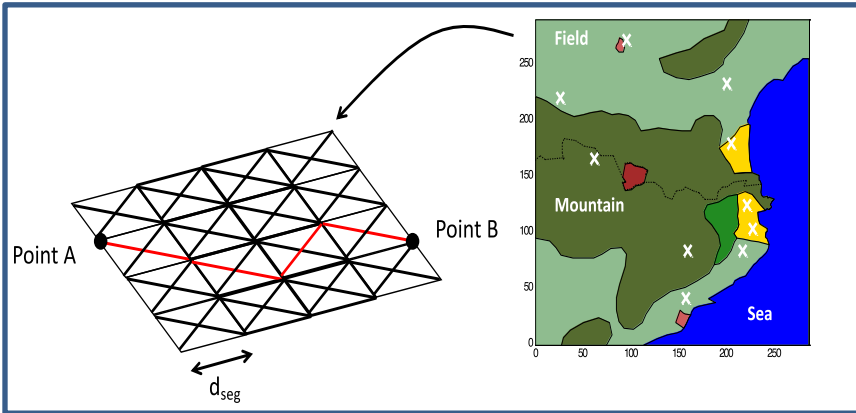
Landscape impact modelling
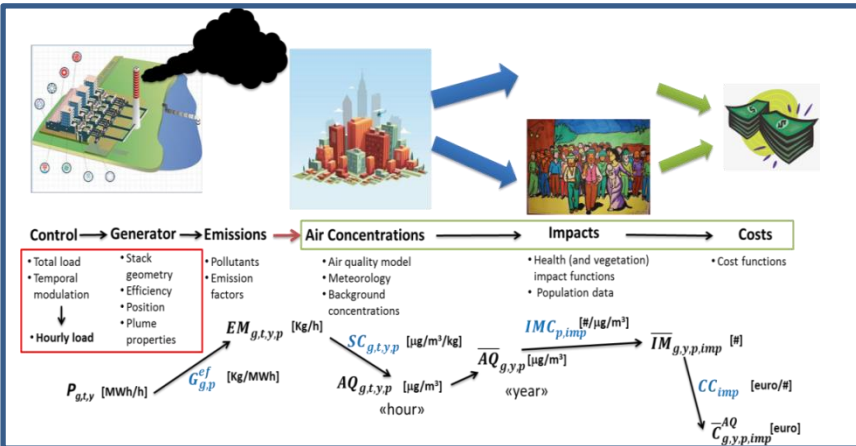
Air quality modelling
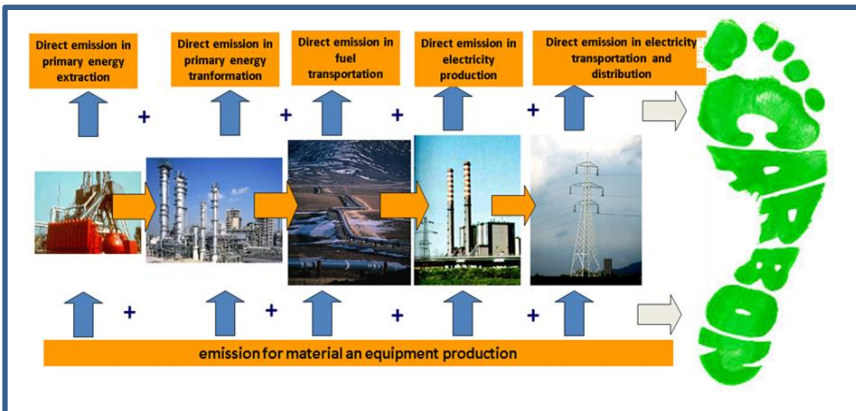
Carbon footprint modelling

Grids modeling
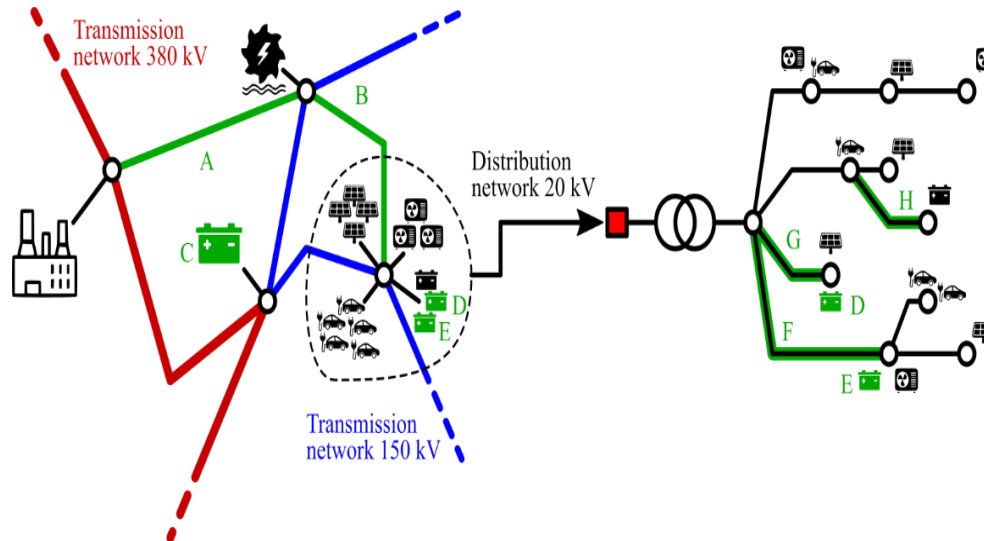
In order to maintain computational tractability, linearized models are adopted:
- DC approximation for transmission grids
- linearized approach (DISTFLOW-like) simplifying but not eliminating reactive power for distribution grids

Simulating real distribution networks in detail would result in an unmanageable complicacy.

Synthetic distribution grids are generated on the basis of few metrics/statistics which can be easily extracted from the analysis of real networks.

Flexible load modeling

upward and downward Demand Shifting

voluntary reduction (Not Consumed Energy)

involuntary reduction (Load Curtailment)

$$P_{u,t,y}^{flex} = P_{u,t,y}^{ref} + \Delta P_{u,t,y}^{ds,up} - \Delta P_{u,t,y}^{ds,dn} - \Delta P_{u,t,y}^{nce} - \Delta P_{u,t,y}^{lc}$$

$P_{u,t,y}^{ref}$
reference demand

$$\left.\begin{array}{l} P_{u,t,y}^{flex} \geq 0 \\[6pt] 0 \leq \Delta P_{u,t,y}^{ds,up} \leq \Delta_{u,t,y}^{ds,up,max} \\[6pt] 0 \leq \Delta P_{u,t,y}^{ds,dn} \leq \Delta_{u,t,y}^{ds,dn,max} \\[6pt] 0 \leq \Delta P_{u,t,y}^{nce} \leq \Delta P_{u,t,y}^{nce,max} \\[6pt] 0 \leq \Delta P_{u,t,y}^{lc} \leq P_{u,t,y}^{ref} \end{array}\right\}$$ bounds on variables

upward demand shifted $\Delta P_{u,t,y}^{ds,up}$

$P_{u,t,y}^{flex}$ active power consumption

$\Delta P_{u,t,y}^{ds,dn}$ downward demand shifted

$\Delta P_{u,t,y}^{lc}$ load curtailment

$\Delta P_{u,t,y}^{nce}$ not consumed power

$$\sum_{t \in \{\tau - T^r + 1, \ldots, \tau\}} \left(\Delta P_{u,t,y}^{ds,up} - \Delta P_{u,t,y}^{ds,down} \right) = 0 \quad \forall \tau : \tau \bmod T^r = 0$$
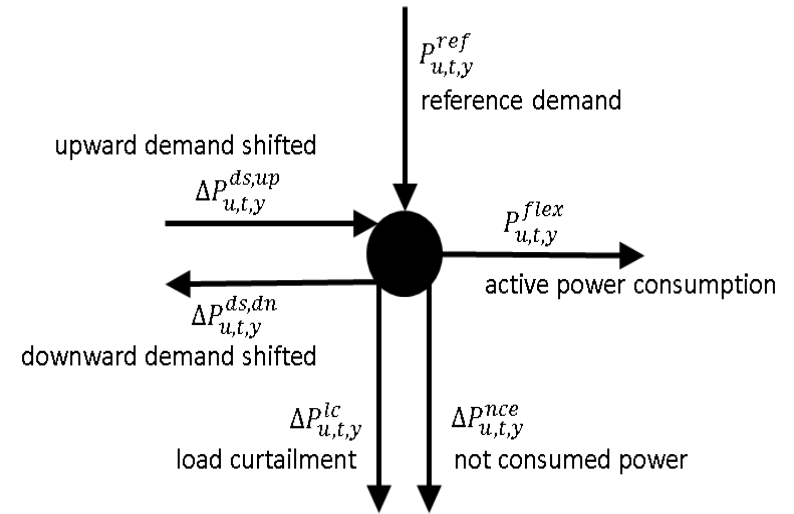
upward and downward demand shifts are rebalanced every T^r periods

Storage modeling

$$E_{j,y}^{max} x_{j,t,y} = (1 - dr_{j,y})^{\Delta t} E_{j,y}^{max} x_{j,t-1,y} + \Delta t \left(\eta_{j,y}^{abs} P_{j,t,y}^{abs} - \frac{P_{j,t,y}^{inj}}{\eta_{j,y}^{inj}} + \xi_{j,t,y} \right)$$

energy stored at time t self-discharge   energy stored at time $t-1$ energy absorbed from network   energy injected into network   exogenous term

maximum content $E_{j,t,y}^{max}$

energy level $x_{j,t,y}$

conversion losses

provided power $\xi_{j,t,y} \geq 0$

$\eta_{j,t,y}^{abs} P_{j,t,y}^{abs}$

$P_{j,t,y}^{abs}$

demander power $\xi_{j,t,y} \leq 0$

$\frac{P_{j,t,y}^{inj}}{\eta_{j,t,y}^{inj}}$

$P_{j,t,y}^{inj}$

conversion losses

storage self-discharge
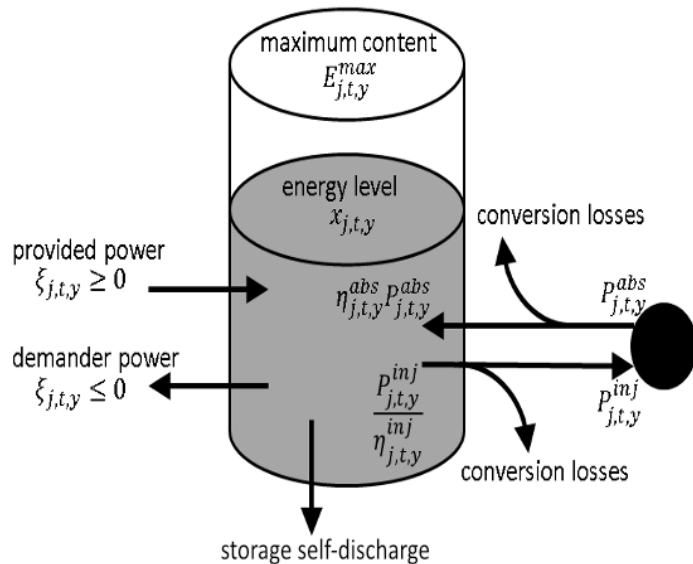
$$E_{jc,y}^{min} \leq E_{jc,y}^{max} x_{jc,t,y} \leq E_{jc,y}^{max}$$ bounds to energy level x

$$0 \leq P_{jc,t,y}^{abs} \leq P_{jc,y}^{abs,max}$$ bounds on power absorbed from network

$$0 \leq P_{jc,t,y}^{inj} \leq P_{jc,y}^{inj,max}$$ bounds on power injected into network

Stochastic OPF approach

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#timesteps: 8760 hours

#nodes

P_{1load}
P_{1gen}

...

P_{4load}
P_{4gen}

#MC years

1h
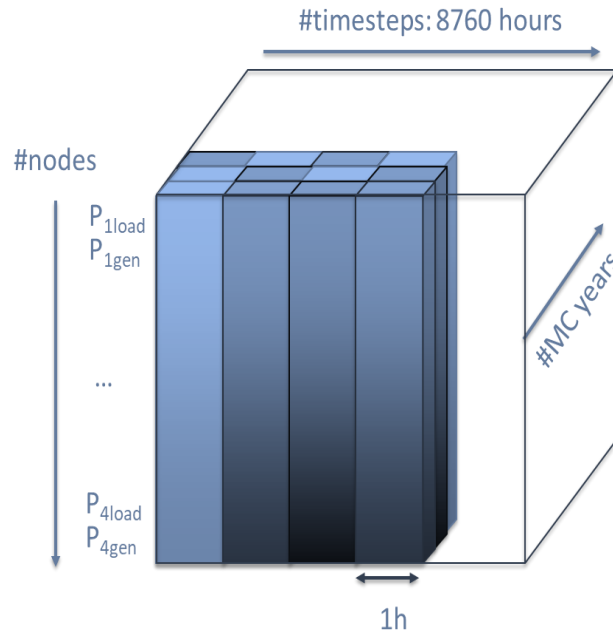
Climate variants of 35 years (variability of RES time series and load time series) are considered in the framework of a stochastic optimisation.

The number of combinations is reduced to two by using **clustering-based scenario reduction techniques**.

Adopting a Monte Carlo approach would present a modeling problem: if every Monte Carlo run is executed separately, then investment decisions are taken separately and there is a problem in putting together results that can be substantially diverging.

So, the dispatch costs of the different variants are weighted together in the target function, each with their own probability (**stochastic optimization**).

In order to retain numerical tractability, the dispatch calculation of the different variants is split by using the **Benders' decomposition**. Such methodology allows to decompose a master problem dealing with the investment decisions from the optimum dispatch calculation for each Monte Carlo variant and for all target years.

The Benders decomposition technique applied to FlexPlan
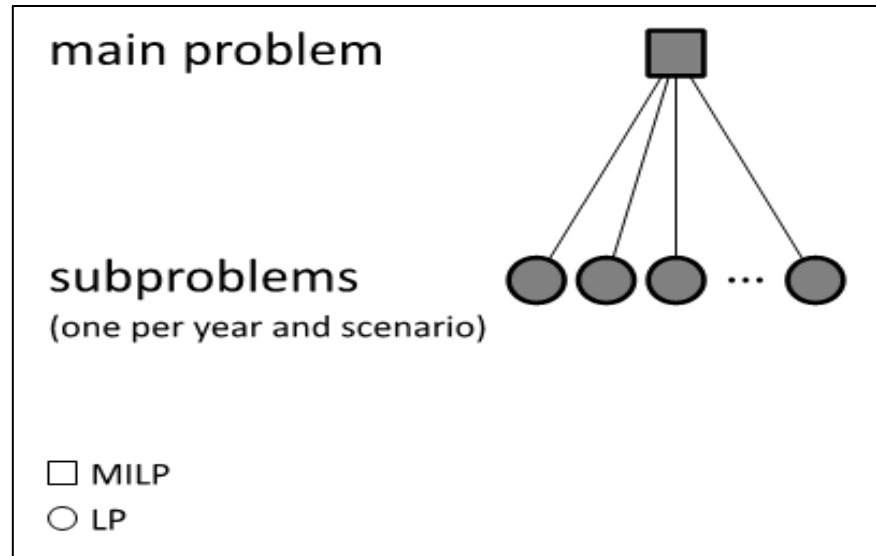
- **Main problem:**
    - optimizes **investment** (integer) variables
    - passes a **decision** to subproblems
        - The value of the investment variables is **fixed**
- **Subproblems:**
    - optimize **operation** (continuous) variables
    - pass back a **cut** to the main problem
        - The intersection of the cuts is a **surrogate** of the operational cost modeled by the subproblems
- Problems can be represented in a **tree** graph
    - Traversal policy: step back and forth between the main problem and the subproblems

FlexPlan proposes a new way to coordinate T&D planning

FlexPlan

TSO/DSO planning coordination	
PROS 👍	👎 **CONS**
• Better exploitation of flexibility resources: distribution resources can provide congestion management for transmission	• Complicated to set up for the number of resources to consider and the number of network constraints
• Higher social welfare: higher market allocation efficiency	• Potential problems of numerical tractability
• Higher liquidity and reduced possibility to exercise market power	• Complexity in the management of the interface between TSO and DSO: need to set up a cooperation protocol

FlexPlan proposes an integrated TSO/DSO protocol able to limit computation complexity as well as ensure a cooperation between TSO and DSO which only requests to exchange a limited amount of data. An integrated T&D planning could be very profitable for increasing social welfare and maximizing services availability (from distribution to transmission). However, there is a **need to cope with numerical complexity** and with the **necessity to coordinate the action of two distinct subjects (TSO and DSO) so as to define a protocol allowing to minimize data exchange** and grant a certain autonomy for each of them. The procedure defined by FlexPlan can be a first step in this direction. The FlexPlan approach is able to act on both these aspects.

FlexPlan proposes a new way to coordinate T&D planning

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Original distribution network
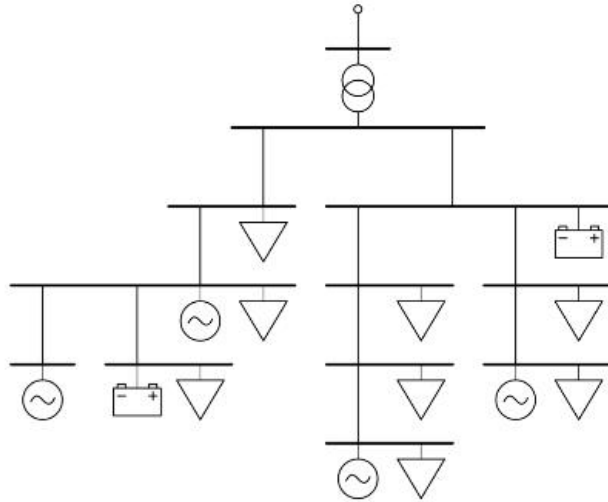
Surrogate model
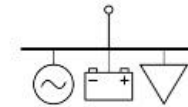
Components
- one generator
- one storage device
- one flexible load

Component parameters such that:
- feasibility *implies* feasibility in original model
- cost *approximates* cost in original model

The grid model is decomposed into TNEP and DNEP.
1. Compute one surrogate model for each distribution network. The surrogate includes possible investments needed for distribution alone
2. Run TNEP problem with the surrogate distribution networks attached to calculate optimal solution for transmission network, costs related to transmission network, power exchanges between transmission and distribution networks
3. Fix power exchanges and run DNEP problem for each distribution network to calculate optimal solution for distribution networks and costs related to distribution networks

The pre-processor

Non-expanded OPF	→ Lagrange multipliers →	Pre-processor	→ Planning candidates →	Planning tool

- The planning tool needs to receive as an input the planning candidates for the three years (2030, 2040, 2050) and for each node.

- This input is provided by a software tool (pre-processor) that ranks for each node the suitability of different kinds of investments (new lines/cables, storage elements, flexible management of big loads

- To do so, the pre-processor exploit the information provided by Lagrange multipliers of line transit constraints and nodal power balance of a non-expanded minimum cost OPF (they provide information on how much the target function would improve as a consequence of a unit relaxation of the constraint).

Pre-processor flow-chart (overview)

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- Congestion severity is determined by:
  - its duration (number of hours)
  - the value of the Lagrange Multiplier
  - the different climatic variants are weighed with their probabilities
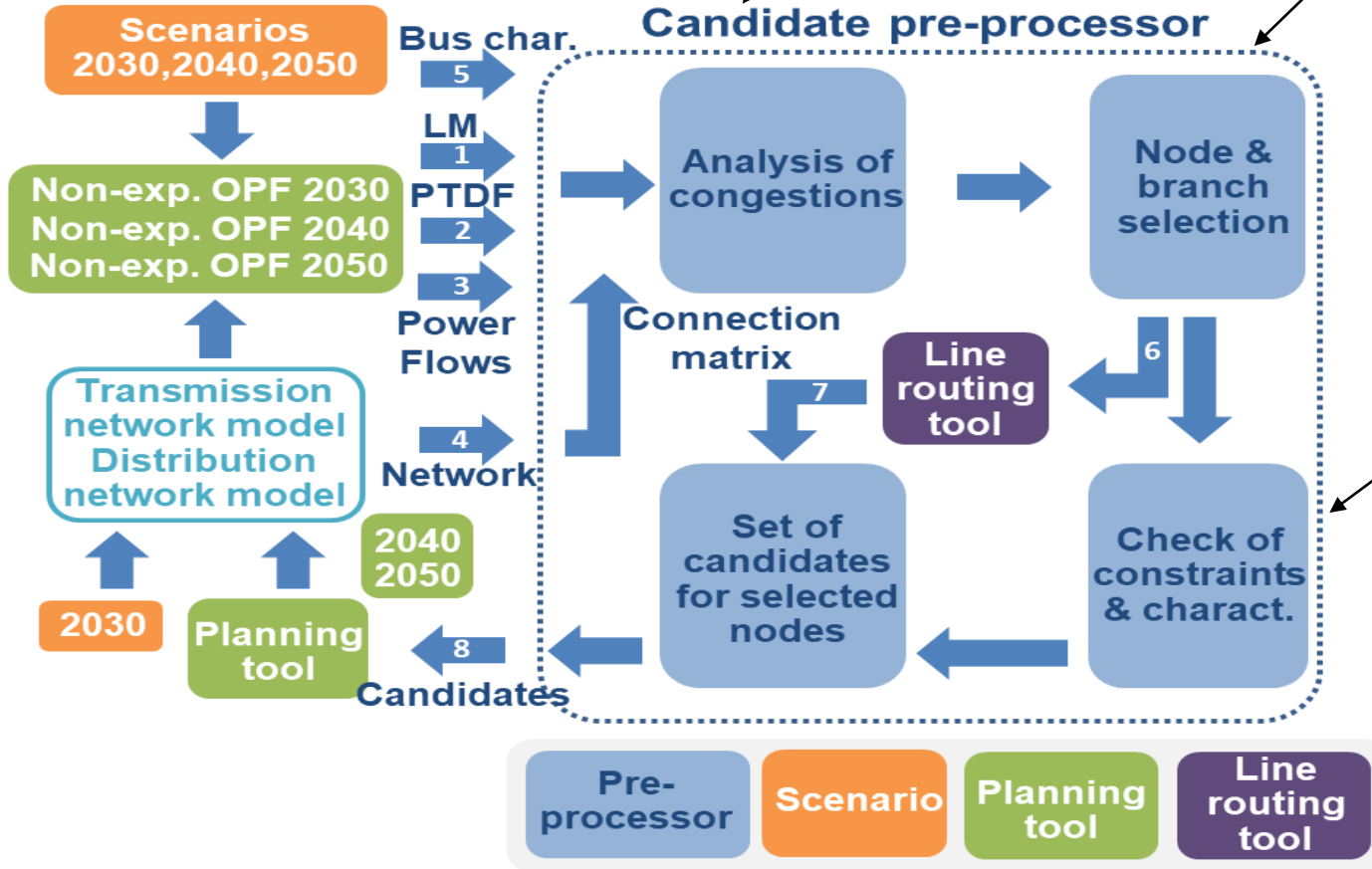
- For lines: select those with highest LM; add other lines with "corridor" analysis
- For storage and DSM, elect node with highest LMP among the two extremes of the congested lines
- Possibility to force candidates (for new corridors)

- Analysis of additional constraints on nodes, depending on technologies

Scenarios 2030,2040,2050

Non-exp. OPF 2030
Non-exp. OPF 2040
Non-exp. OPF 2050

Transmission network model
Distribution network model

2040 2050

2030

Planning tool

Bus char. 5
LM 1
PTDF 2
3
Power Flows
Network 4

Candidate pre-processor

Analysis of congestions

Node & branch selection

Connection matrix

Line routing tool
6
7

Set of candidates for selected nodes

Check of constraints & charact.

Candidates 8

Pre-processor | Scenario | Planning tool | Line routing tool

A "corridor expansion" approach
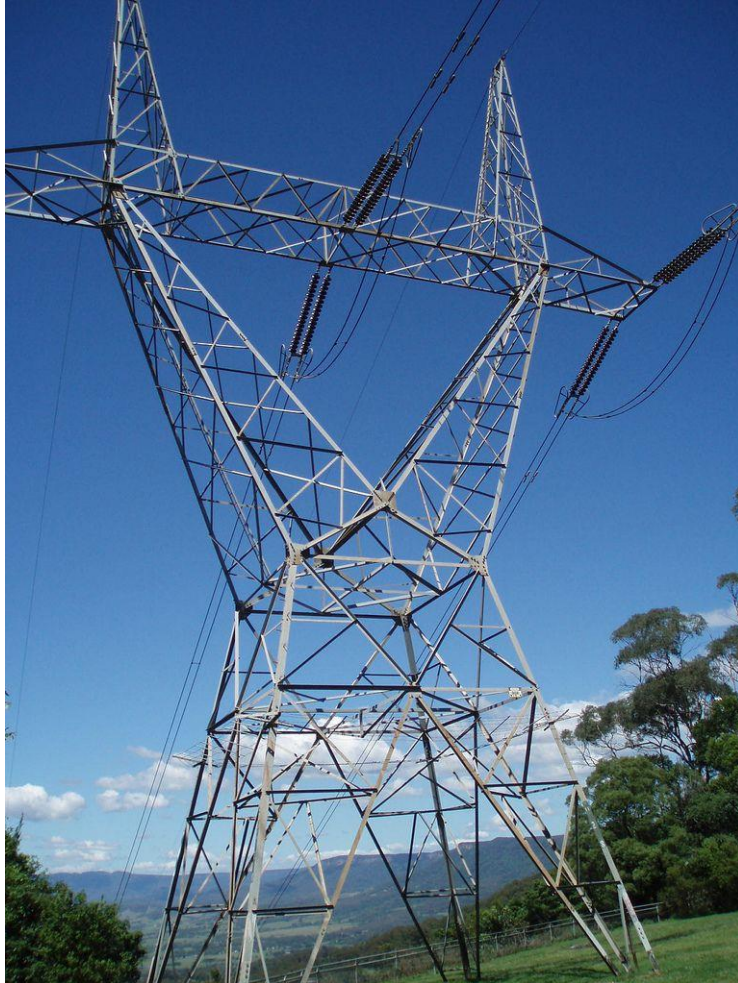
- Determining expansion candidates by looking at Lagrange multipliers (LM) of line transit constraints generates the problem that **by removing a congestion on a line, transits increase and this could create congestion elsewhere** (typically downstream).

- Lines that could saturate in chain should be clusterized with the first one to create what is generically referred to as an "**expansion corridor**".

Interaction between pre-processor and planning tool

FlexPlan

Architecture 1: simple and less computationally demanding, but quite "raw" because 2050 candidates are calculated from the 2025 network.

```
Non-expanded          Pre-processor run      Candidates set for      Planning tool run
2050 OPF         →    at 2050           →    three grid years:  →    (2030, 2040, 2050)
2025 network                                 2050, 2050, 2050
```

Architecture 2: also with low calculation efforts (1 only pass of the planning tool), but still "raw".

```
Non-expanded          Pre-processor run
2030 OPF         →    at 2030           →
2025 network                                \
                                             Reduction of
Non-expanded          Pre-processor run      the three
2040 OPF         →    at 2040           →    candidates          Planning tool run
2025 network                                 sets (if one   →    (2030, 2040, 2050)
                                             candidate is
Non-expanded          Pre-processor run      in more than
2050 OPF         →    at 2050           →    one set, it is
2025 network                                 retained only
                                             in the first
                                             set
```
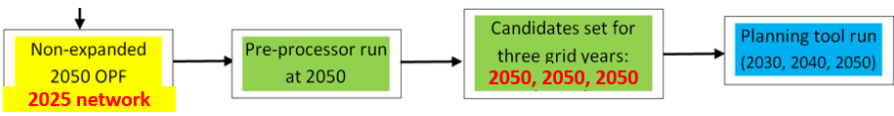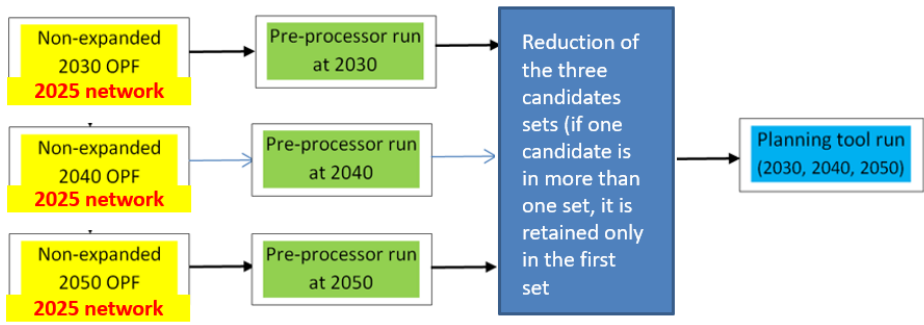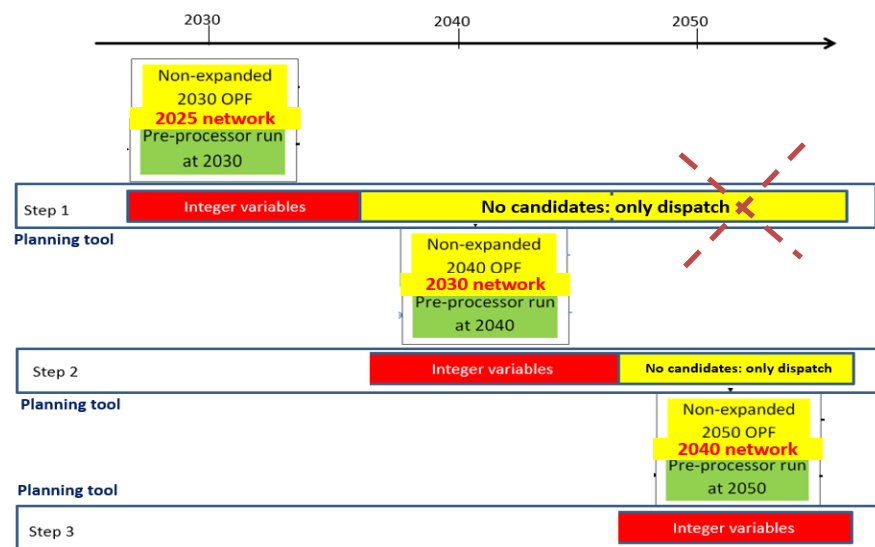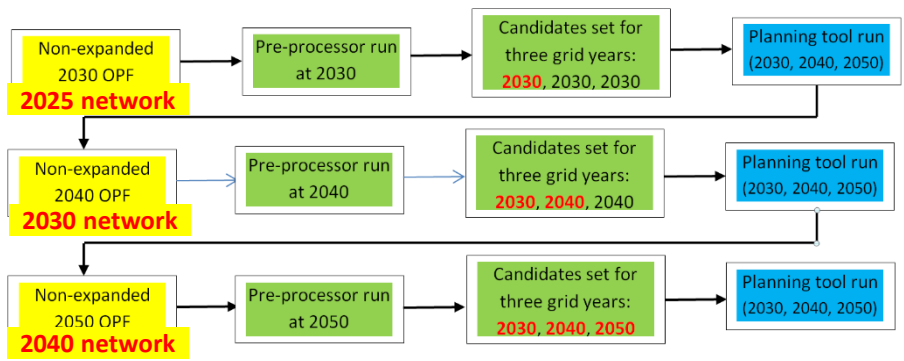
Architecture 3: more complex (3 passes of the planning tool but each with candidates of one single year). Consequences on dispatch for the subsequent decades are still computed.

```
        2030              2040              2050
    ─────●────────────────●────────────────●──────────────→

    Non-expanded
    2030 OPF
    2025 network
    Pre-processor run
    at 2030

Step 1   | Integer variables |    No candidates: only dispatch ✗
Planning tool
                    Non-expanded
                    2040 OPF
                    2030 network
                    Pre-processor run
                    at 2040

Step 2                  | Integer variables | No candidates: only dispatch
Planning tool
                            Non-expanded
                            2050 OPF
                            2040 network
                            Pre-processor run
                            at 2050

Planning tool
Step 3                          | Integer variables |
```

Architecture 4: best heuristics but also the most complex: possibly too demanding from the computational point of view.

```
Non-expanded          Pre-processor run      Candidates set for      Planning tool run
2030 OPF         →    at 2030           →    three grid years:  →    (2030, 2040, 2050)
2025 network                                 2030, 2030, 2030                │
    │                                                                        │
    ↓                                                                        │
Non-expanded          Pre-processor run      Candidates set for      Planning tool run
2040 OPF         →    at 2040           →    three grid years:  →    (2030, 2040, 2050)
2030 network                                 2030, 2040, 2040                │
    │                                                                        │
    ↓                                                                        │
Non-expanded          Pre-processor run      Candidates set for      Planning tool run
2050 OPF         →    at 2050           →    three grid years:  →    (2030, 2040, 2050)
2040 network                                 2030, 2040, 2050
```

# FlexPlan Grid Expansion tool: availability of demo version

- A **video** is available to illustrate the main GUI features (see news item: https://flexplan-project.eu/2022/11/23/flexplan-grid-explansion-tool-gui-look-and-feel/ on the FlexPlan web).

- A **demo version** of the FlexPlan planning tool is available at: https://flexplan.eu.n-side.com/. This demo version has the goal to give the possibility to external stakeholders such as TSOs, DSOs and regulators to access and test the tool with simple test cases. It allows to run and analyze simulations with up to 20 buses (AC or DC buses). Credentials allowing to test this demo version of the software can be requested by writing an email to flexplan@n-side.com.

FlexPlan web and open access resources

FlexPlan

All project publications (deliverables, papers, important presentations) are publicly downloadable from:
https://flexplan-project.eu

The OptimalTransmissionRouting.jl package is a Julia/JuMP package to determine the **optimal transmission system route** considering spatial information. The open access license toolbox and can be found on: https://github.com/Electa-Git/OptimalTransmissionRouting.jl

FlexPlan.jl is a Julia/JuMP **package to carry out transmission and distribution network planning** considering AC and DC technology, storage and demand flexibility as possible expansion candidates. A mixed-integer linear problem is constructed to be solved with any commercial or open-source MILP solver. The open access license toolbox can be found under: https://github.com/Electa-Git/FlexPlan.jl Installation instructions, information regarding problem types and network formulations are provided in the package documentation (https://electa-git.github.io/FlexPlan.jl/dev/).

FlexPlan project workshop in Brussels
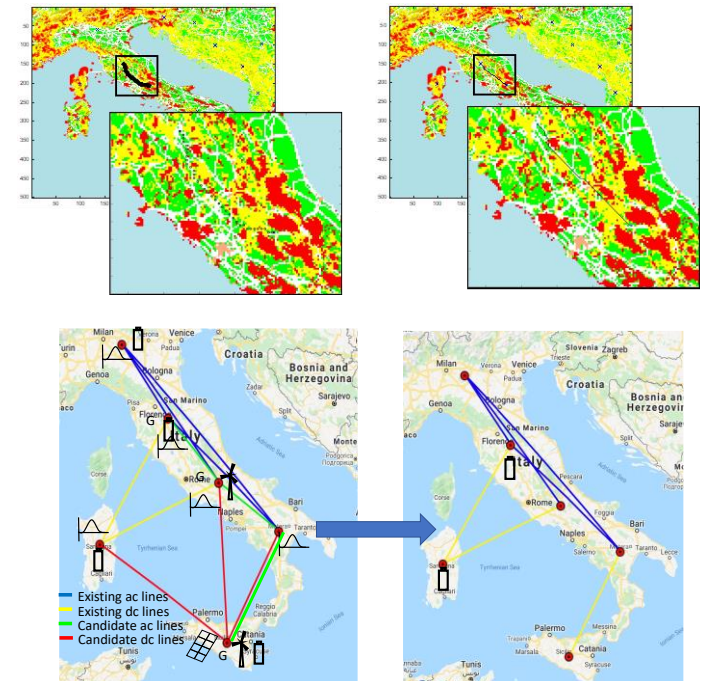
FlexPlan

Final Workshop of the FlexPlan project:
Brussels - 14th February 2023

Location: https://www.l42.be/portfolio-item/live/
Online participation will also be possibile.

Registration requests to:
Gianluigi.Migliavacca@rse-web.it

- 09.00-10.00 - Overview of FlexPlan aim and methodology

- 10.00-11.00 - Showcase of FlexPlan pre-processor and planning tool

- 11.00-12.00 - Results of the pan-European model

- 12.00-13.30 - Lunch time

- 13.30-14.30 - Results of the 6 regional cases

- 14.30-15.15 - Preview of the final regulatory reflections and guidelines

- 15.15-16.15 - General debate on possible up-scalability of the FlexPlan methodologies and tools and about real takeaway for the European stakeholders

- 16.15-16.30 – Wrap-up and final conclusions of the meeting.

Thank you…

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