FlexPlan

Agenda 14th February 2023 (Final Project Workshop)

Venue: Brussels - https://www.l42.be/portfolio-item/live/

- 09.00-10.00 - Overview of FlexPlan aim and methodology (Gianluigi Migliavacca – RSE; Hakan Ergun: KU Leuven)
- 10.00-11.00 - Showcase of FlexPlan pre-processor and planning tool (Maxime Hanot -N-SIDE; Santiago Garcia Lazaro - TECNALIA)
- 11.00-12.00 - Results of the pan-European model (Jawana Gabrielski – TU Dortmund)
- 12.00-13.30 - Lunch time
- 13.30-14.30 - Results of the 6 regional cases (Aleksandr Egorov – R&D NESTER)
- 14.30-15.15 - Preview of the final regulatory reflections and guidelines (Andrei Morch – SINTEF; Dario Siface - RSE)
- 15.15-16.15 - General debate on possible up-scalability of the FlexPlan methodologies and tools and about real takeaway for the European stakeholders (Moderator: Gianluigi Migliavacca - RSE)
- 16.15-16.30 – Wrap-up and final conclusions of the meeting.

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FlexPlan

Final project workshop| 14th February 2023

Overview of the FlexPlan goals and methodology

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Agenda

- Critical aspects of the present grid planning methodologies
- Motivation objectives and partnership of the FlexPlan project
- The planning tool
    - Target function
    - Flexibility modelling
    - Environmental modelling
    - Grids modelling
    - Stochastic OPF approach
    - Benders’s and T&D decomposition
- The pre-processor and its interaction with the planning tool
- Interactions between planning tool and pre-processor
- Planning tool testing and model simplifications
- Availability of FlexPlan toolbox and open access libraries

Critical aspects of the present grid planning methodologies

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- 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)	• **to compensate short lasting congestion created by RES variability the deployment of new lines could prove economically inefficient,** but traditional grid planning disregards the role of flexibility! • **according to Directive (EU) 2019/944 (Art. 32, Art. 40) storage and DSM should become full fledged planning candidates for TSOs and DSOs; according to Regulation (EU) 2022/869 (Art. 13) ENTSO-E's infrastructure gap analysis must "consider with priority all relevant alternatives to new infrastructure" (i.e. include storage and DSM)**: "with-without planning approach" is too limiting to co-evaluate a high number of 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 for an optimal management of decarbonization path	• **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. Most flexible resources are connected to distribution but could provide flexibility to transmission	• **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**.

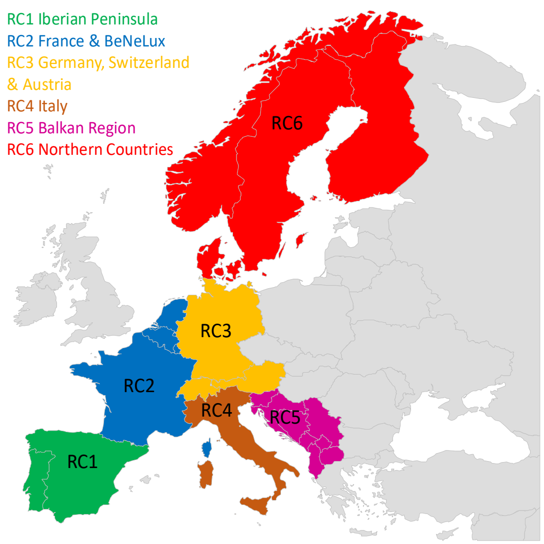
The FlexPlan project

- **Start date: 01.10.2019**
- **End date: 31.03.2023**

… 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.

What FlexPlan achieved

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)



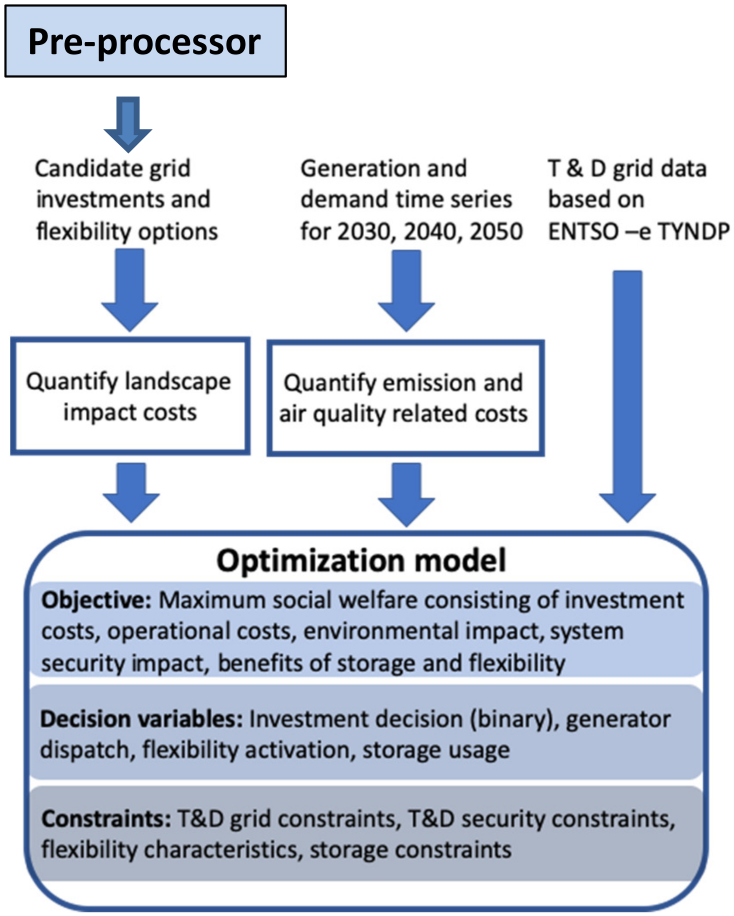
2 – Scenario analysis 2030-40-50 - New methodology applied to analyse **six regional grid planning scenarios at 2030-2040-2050.** A **pan-European scenario** has delivered border conditions to initialize in a coherent way the 6 regional cases.

3 – Regulatory guidelines - on top of the new planning methodology, FlexPlan provided some regulatory reflections resulting in a set of indications for NRAs on which barriers should be removed for the implementation of the new methodology.

Partnership of the FlexPlan project

- 13 Partners
- 8 European Countries
- 3 TSOs
- 1 Major DSO Concern

The new planning tool



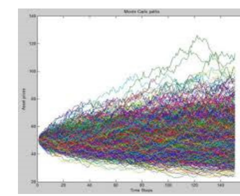
- Best planning strategy with a limited number of expansion options (mixed-integer, sequential OPF)

- T&D coordinated planning; distribution grids (MT) represented by synthetic networks

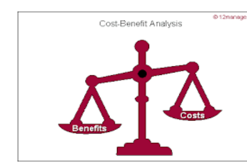
- Embedded environmental analysis (air quality, carbon footprint, landscape constraints)

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

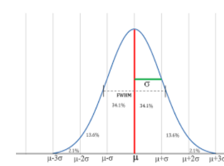
- Probabilistic OPF using 35 climate year variants (RES and load time series) reduced to 2 variants of 4 yearly weeks (one per season) by using clustering-based scenario reduction techniques



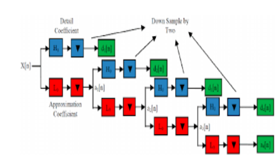
- Full incorporation of CBA criteria into the target function



- 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

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

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

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

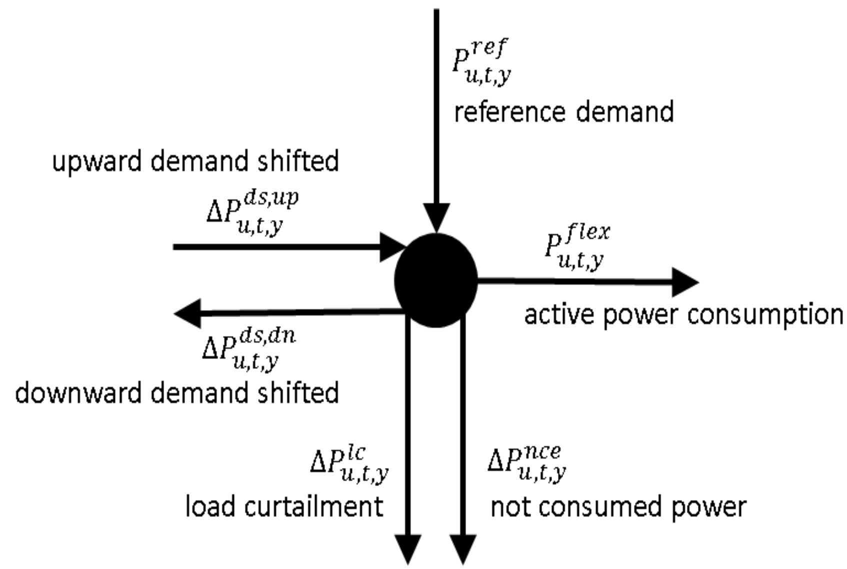
Flexible load modeling

upward and downward Demand Shifting

voluntary reduction (Not Consumed Energy)

involuntary reduction (Load Curtailment)

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



$$P_{u,t,y}^{flex} \geq 0$$
$$0 \leq \Delta P_{u,t,y}^{ds,up} \leq \Delta_{u,t,y}^{ds,up,max}$$
$$0 \leq \Delta P_{u,t,y}^{ds,dn} \leq \Delta_{u,t,y}^{ds,dn,max}$$
$$0 \leq \Delta P_{u,t,y}^{nce} \leq \Delta P_{u,t,y}^{nce,max}$$
$$0 \leq \Delta P_{u,t,y}^{lc} \leq P_{u,t,y}^{ref}$$

bounds on variables

$$\sum_{t \in \{\tau - T^r + 1, \dots, \tau\}} \left(\Delta P_{u,t,y}^{ds,up} - \Delta P_{u,t,y}^{ds,down} \right) = 0 \quad \forall \tau : \ \tau \bmod T^r = 0$$

upward and downward demand shifts are rebalanced every T^r periods

Storage modeling

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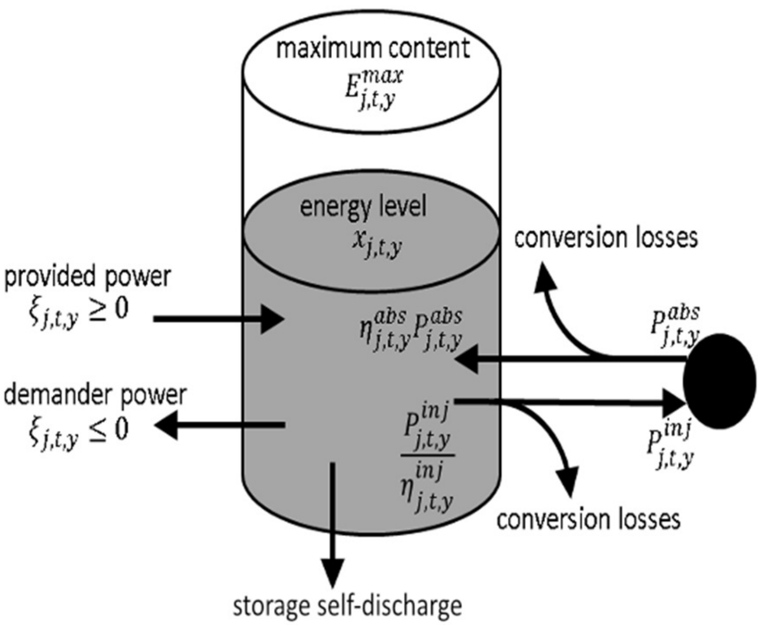
$$E_{j,y}^{max} x_{j,t,y} = (1 - dr_{j,y})^{\Delta t} E_{j,y}^{max} x_{j,t-1,y} + \Delta t \left(\eta_{j,y}^{abs} P_{j,t,y}^{abs} - \frac{P_{j,t,y}^{inj}}{\eta_{j,y}^{inj}} + \xi_{j,t,y} \right)$$

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

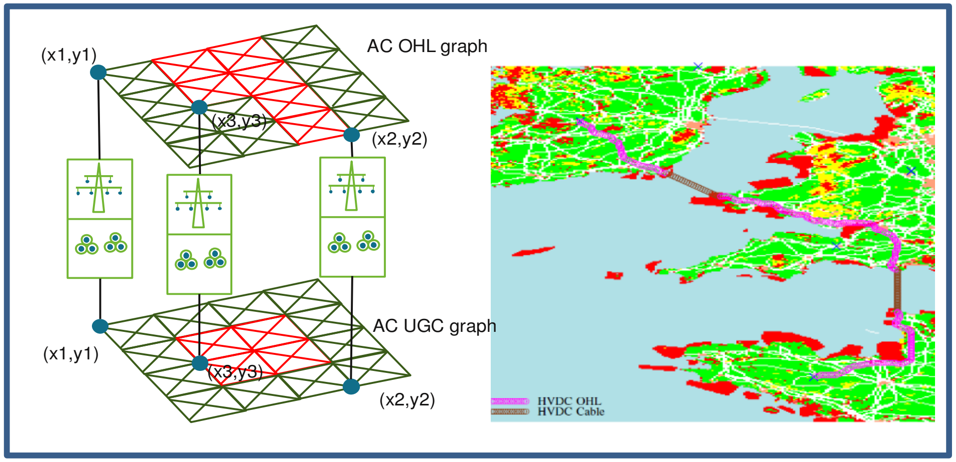


$E_{jc,y}^{min} \leq E_{jc,y}^{max} x_{jc,t,y} \leq E_{jc,y}^{max}$ bounds to energy level *x*

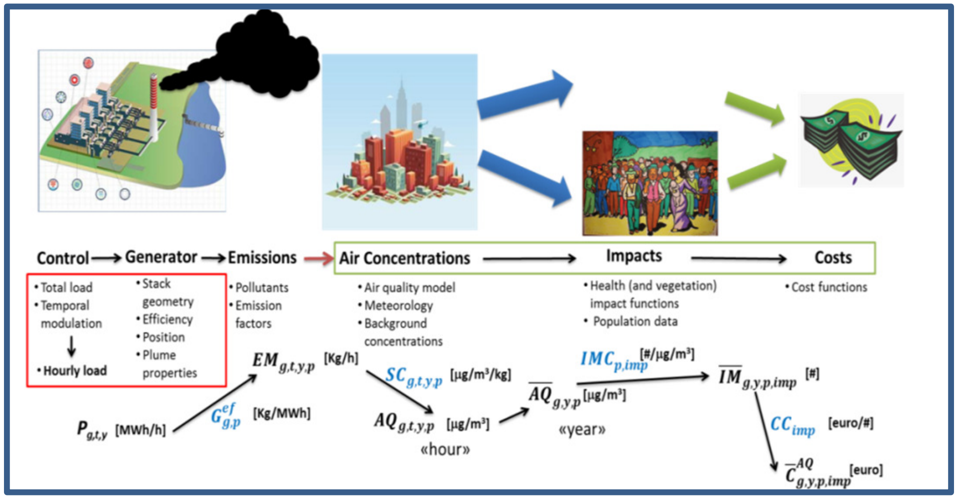
$0 \leq P_{jc,t,y}^{abs} \leq P_{jc,y}^{abs,max}$ bounds on power absorbed from network

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

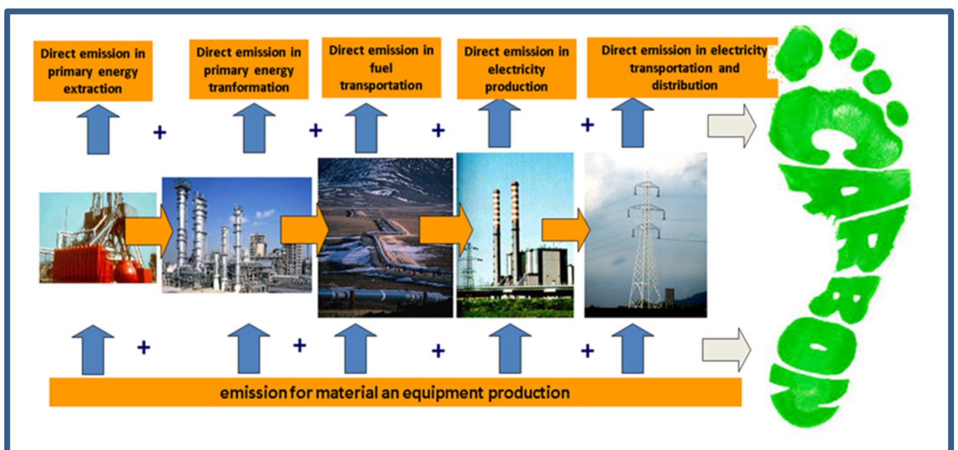
Modeling of environmental factors



Landscape impact modelling:
Using optimal routing routing algorithm quantifying landscape impact cost for OHL and cable investments



Air quality modelling:
Linearized model quantifying air quality impact related costs in dependence of generation



Carbon footprint modelling:
CO_2 emission cost of power generation as direct input, CO_2 impact of new grid investments using LCA

Transmission and distribution grid modeling

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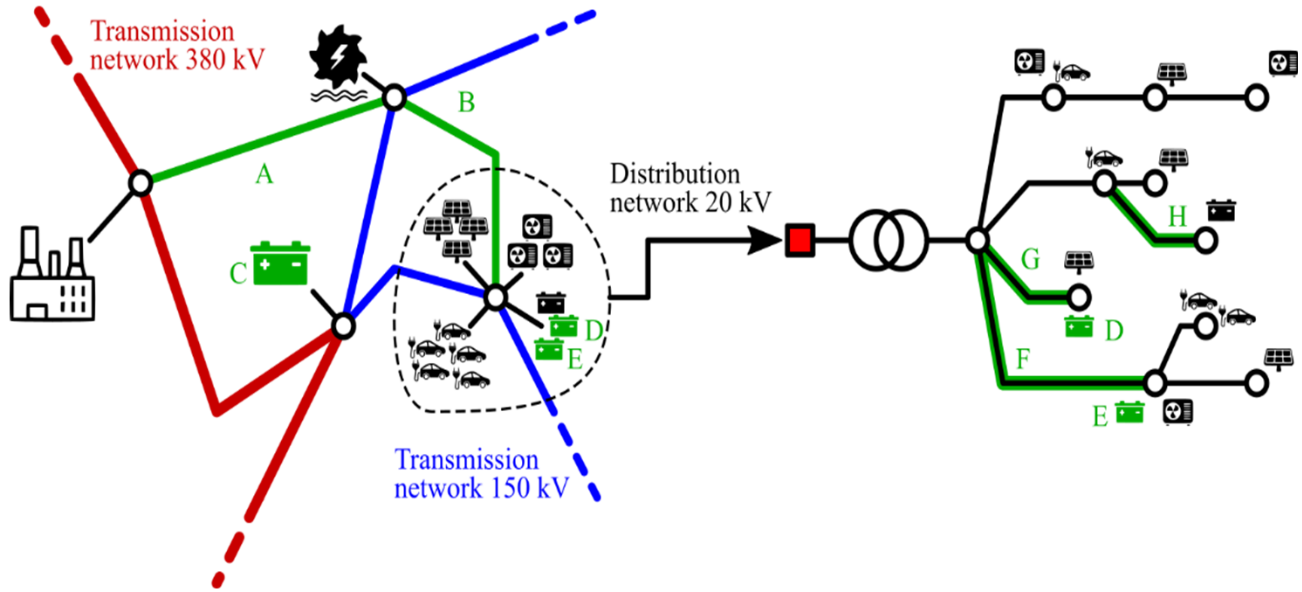

In order to maintain computational tractability, linearized models are adopted:

- DC approximation for AC/DC 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.

Stochastic OPF approach

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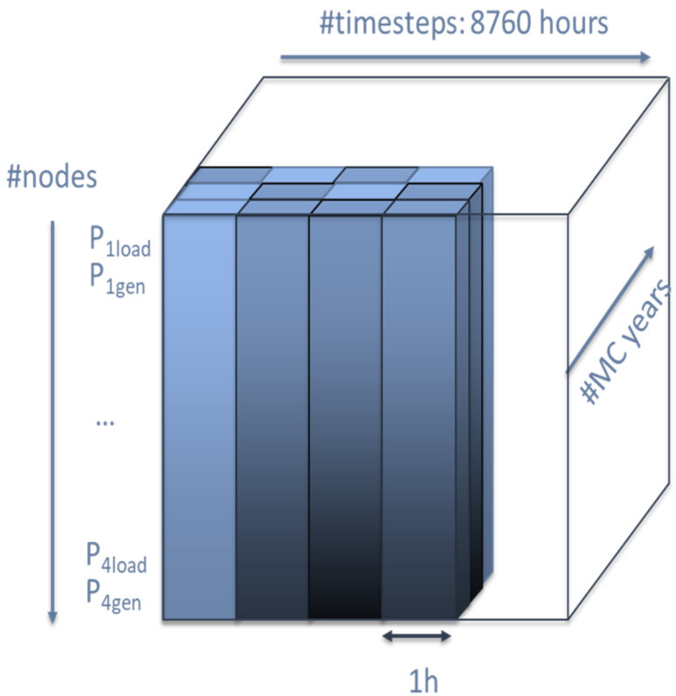

Climate variants of 35 years (variability of RES time series and load time series) are considered in the framework of a stochastic optimisation.

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

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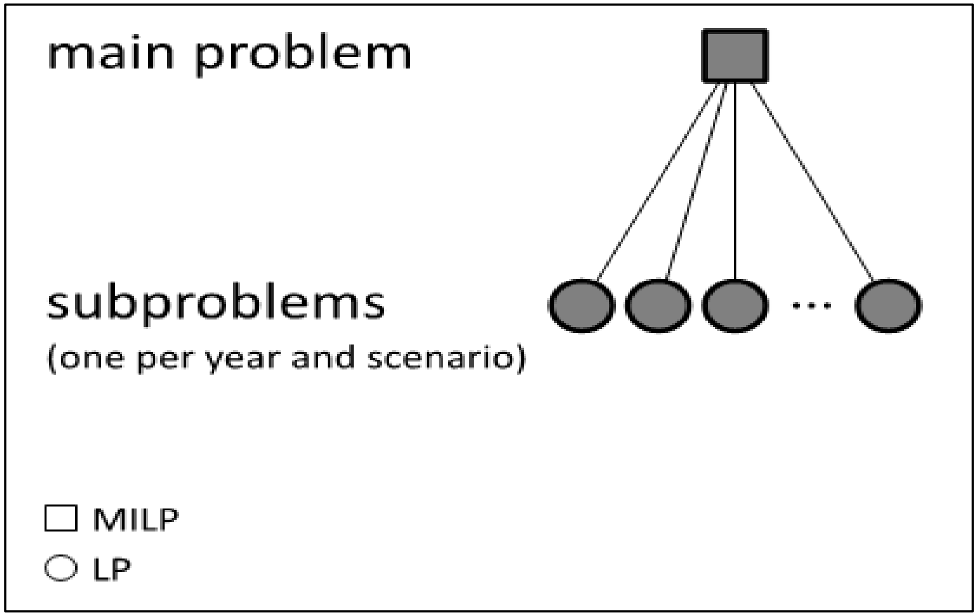

- **Main problem:**
  optimizes **investment** (integer) variables
  passes a **decision** to subproblems
    The value of the investment variables is **fixed**
- **Subproblems:**
  optimize **operation** (continuous) variables
  pass back a **cut** to the main problem
    The intersection of the cuts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

FlexPlan proposes a new way to coordinate T&D planning

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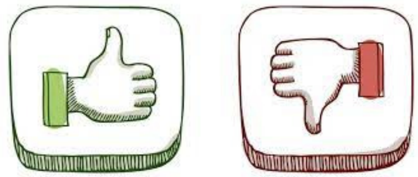
TSO/DSO planning coordination



PROS

- Better exploitation of flexibility resources: distribution resources can provide congestion management for transmission
- Higher social welfare: higher market allocation efficiency
- Higher liquidity and reduced possibility to exercise market power

CONS

- Complicated to set up for the number of resources to consider and the number of network constraints
- Potential problems of numerical tractability
- 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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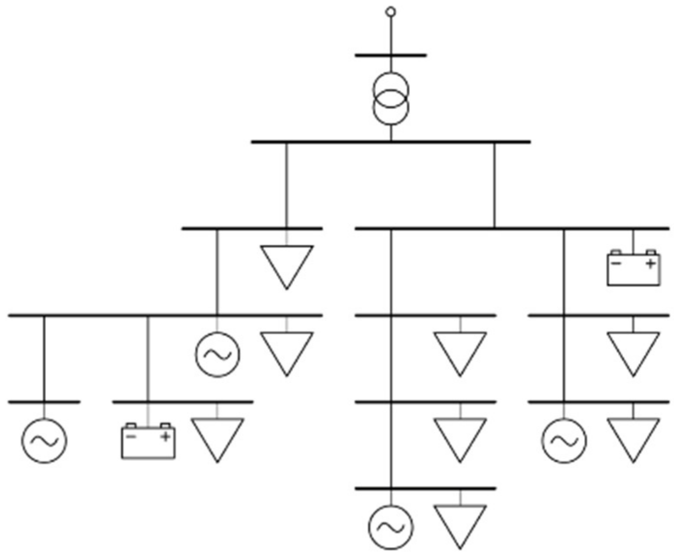
Original distribution network



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

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- 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).

A “corridor expansion” approach

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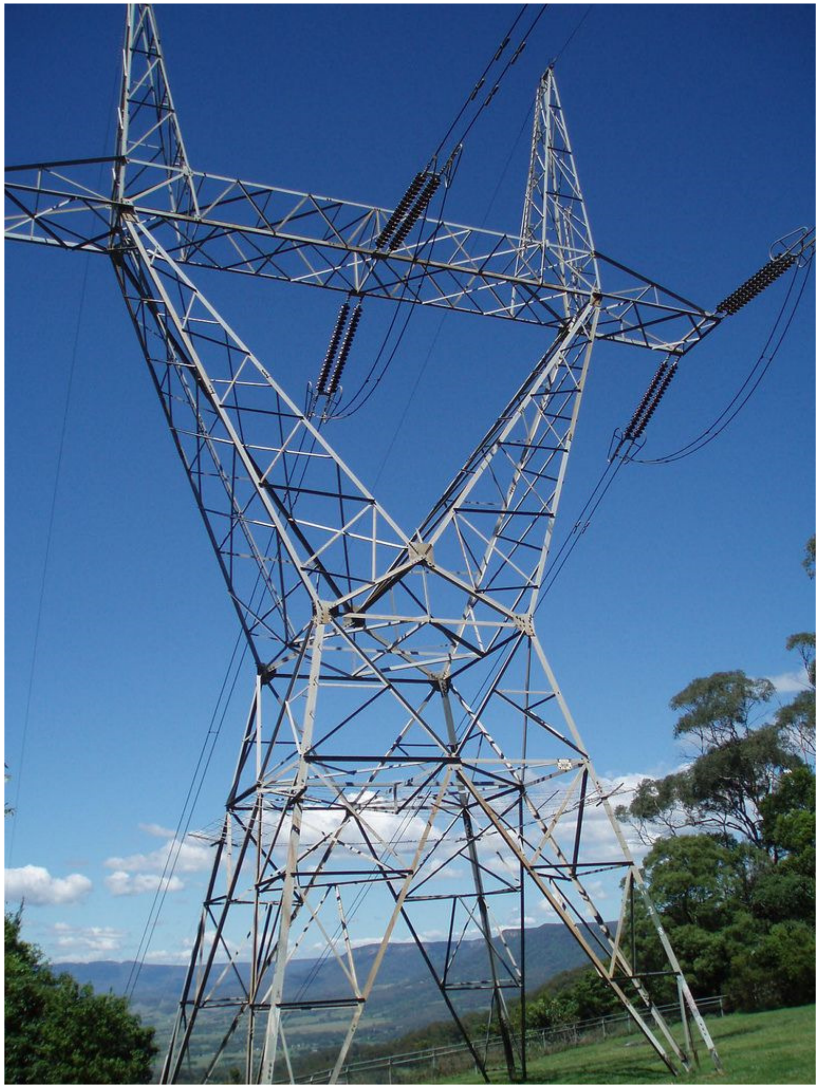
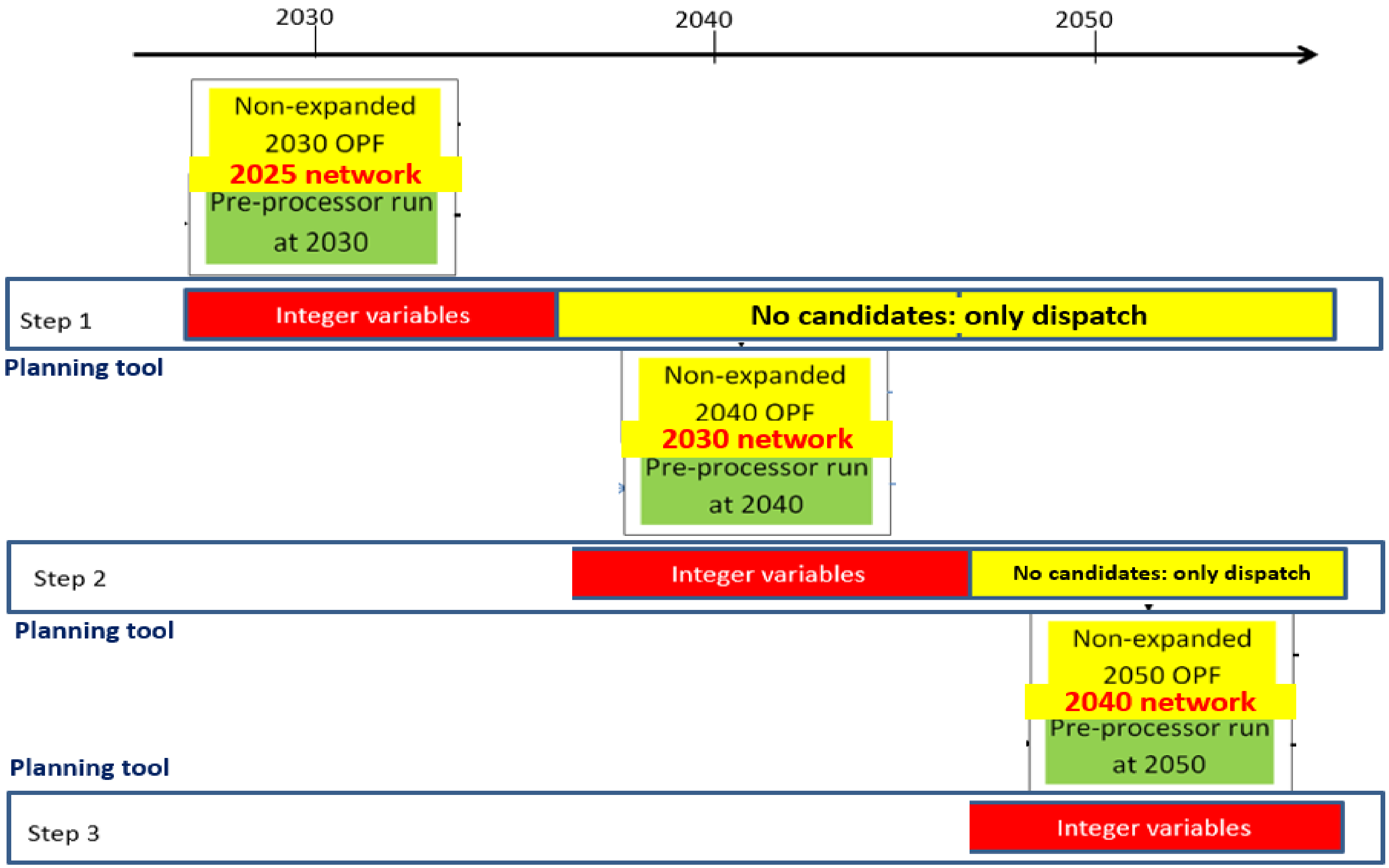


- Determining expansion candidates by looking at Lagrange multipliers (LM) of line transit constraints generates the problem that **by removing a congestion on a line, transits increase and this could create congestion elsewhere** (typically downstream).

- 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 GEP tool and pre-processor

- Solving 2030, 2040 and 2050 altogether need to have candidates for all three decades, but running a non-expanded OPF for 2040 or 2050 to feed the pre-processor implies the previous decades problem is already solved, which is not…
- To solve this *chicken and egg problem* while avoiding a sequential 2030-2040-2050 problem solving (sub-optimal) requires to find out some “efficient” heuristics.
- The best choice is an algorithm able to preserve the maximum coupling between the decades while relaxing just what needed to get an acceptable computational burden.



Planning tool testing and model simplifications

Dealing with the limited time/hardware resources of FlexPlan

Even though the FlexPlan GEP tool has been optimized in order to manage real-size systems, **time and budget limitations prevented to push the development in the direction of parallel calculation** so as to parallelize the calculations of the different optimizations over different PCs. By contrast, the need to run in parallel 6 regional cases brought to choose deploying the SW on **AWS servers**, which implement, however, a rigid memory management (no swap).

Due to that, **important simplifications were needed** to run very large systems (thousands of nodes) while considering over 100 candidates per grid year:

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

- **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)
- **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)

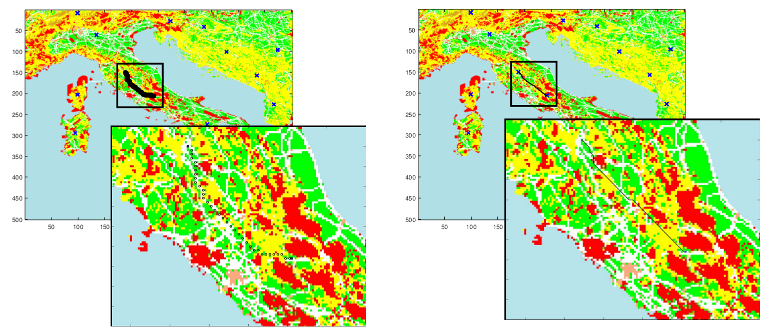
FlexPlan Grid Expansion tool: availability of demo version

- 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.

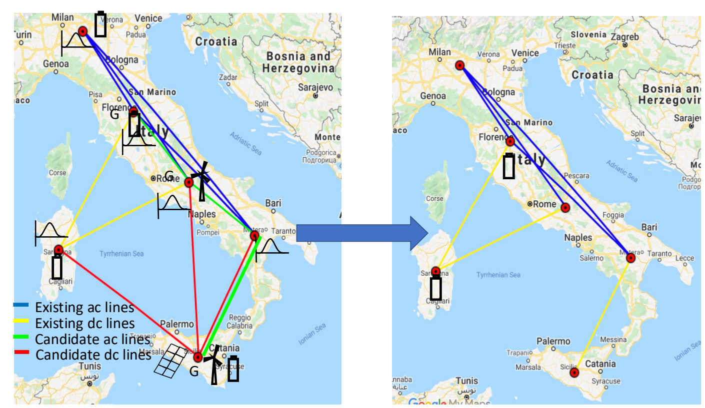
FlexPlan web and open access resources

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/).



Thank you…

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