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FlexPlan

Meeting with ENTSO-E| 18th February 2021

The FlexPlan project

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Agenda

- Motivation of the FlexPlan project
- FlexPlan partnership
- Goals of the project
- The planning tool
  - Target function
  - Reliability model
  - Environmental modelling
  - Grids modelling
  - Flexible loads and storage modelling
  - Monte Carlo approach and Benders’ decomposition
- The pre-processor
  - Corridor expansion approach
- Interactions between planning tool and pre-processor
- Pan-European and regional scenarios generation
- Some preliminary ideas for the planning guidelines
- The FlexPlan web

- Answers to the questions by ENTSO-E

Motivation of the FlexPlan project

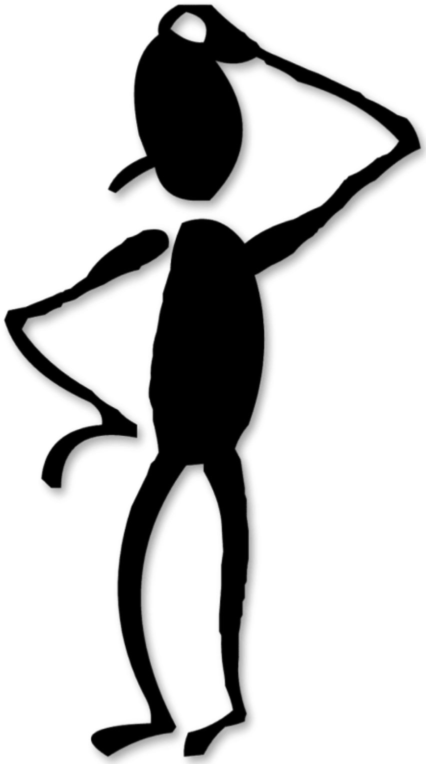
- High-speed deployment of RES (challenging European target: 32% at 2030) is making T&D planning more and more complex and affected by a high level of uncertainty

- Grid investments are capital intensive and the lifetime of transmission infrastructure spans several decades: when a new line is commissioned it might be already partially regarded as a stranded cost

- Building new lines meets more and more hostility from the public opinion, which makes planning activities even longer and affected by uncertainties

- Variable flows from RES are generating a new type of intermittent congestion which can sometimes be well compensated with system flexibility: investments in a new line would not be justified.

- There is an on-going debate on the employment of storage technologies and system flexibility to make the RES grid injection more predictable ("virtual power plant")



The FlexPlan project

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- **Start date: 01.10.2019**
- **End date: 30.09.2012**

… 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

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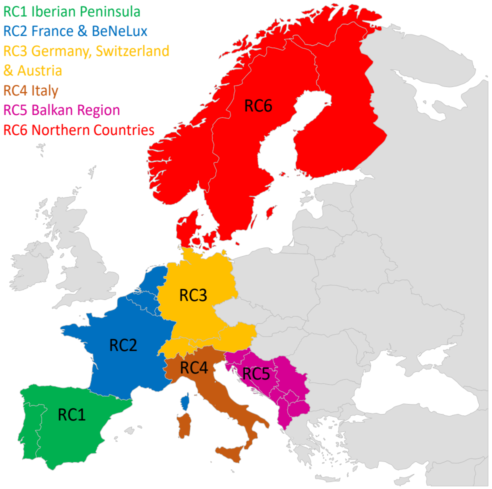
1 – New planning methodology - Creation of a **new tool for optimizing T&D grid planning**, considering the **placement of flexibility elements** located both in transmission and distribution networks **as an alternative to traditional grid planning**: in particular, storage, PEV, demand response)



2 – Scenario analysis 2030-40-50 - New methodology applied to analyse **six regional grid planning scenarios at 2030-2040-2050.** A **pan-European scenario** 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 new planning tool

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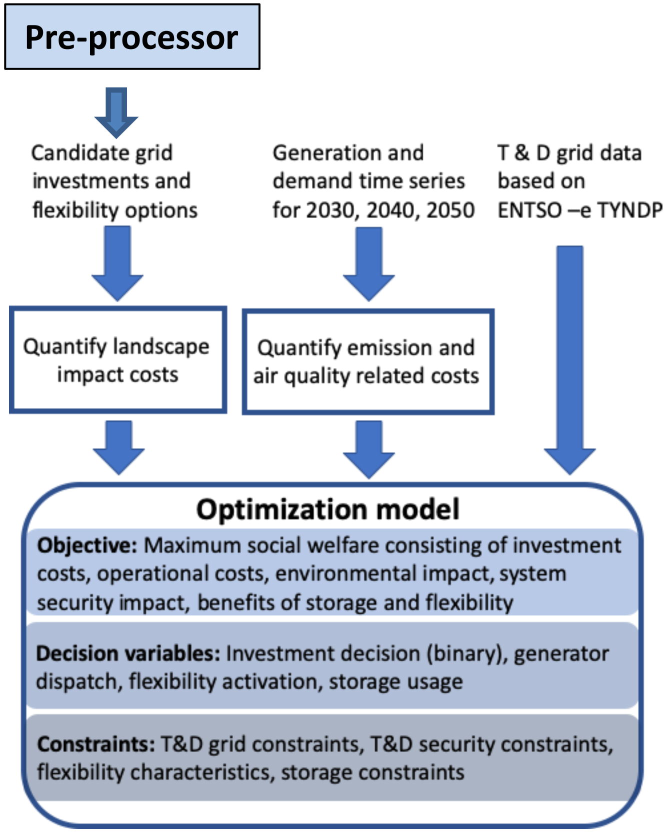


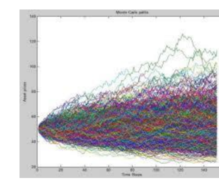
- Best planning strategy with a limited number of expansion options (mixed-integer, sequential OPF)

- T&D integrated planning

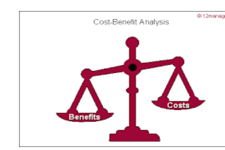
- Embedded environmental analysis (air quality, carbon footprint, landscape constraints)

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

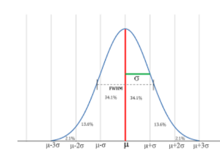
- Yearly climate variants (variability of RES time series and load time series) taken into account by a Monte Carlo process; the number of combinations reduced by using clustering-based scenario reduction techniques.



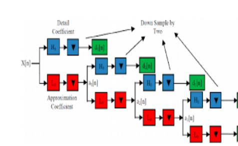
- Full incorporation of CBA criteria into the target function



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



- Numerical *ad hoc* decomposition techniques to reduce calculation efforts



The new planning tool: optimization target function

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y = 2030, 2040, 2050

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

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

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

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

The new planning tool: optimization target function

Discount factor for operational costs: since each simulated year represents a decade, it counts for 10 years, each with its discount factor; thus $f_y^{d,o}$ represents the cumulate discount factor, that is

$$f_y^{d,o} = \sum_{\tau=y:y+9} \frac{1}{(1+r^d)^{\tau-\tilde{y}}}$$

$\tilde{y}$ is the reference year for the discount factor evaluation (nominally 2030)

y = 2030, 2040, 2050

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

Discount factor for the investment costs:

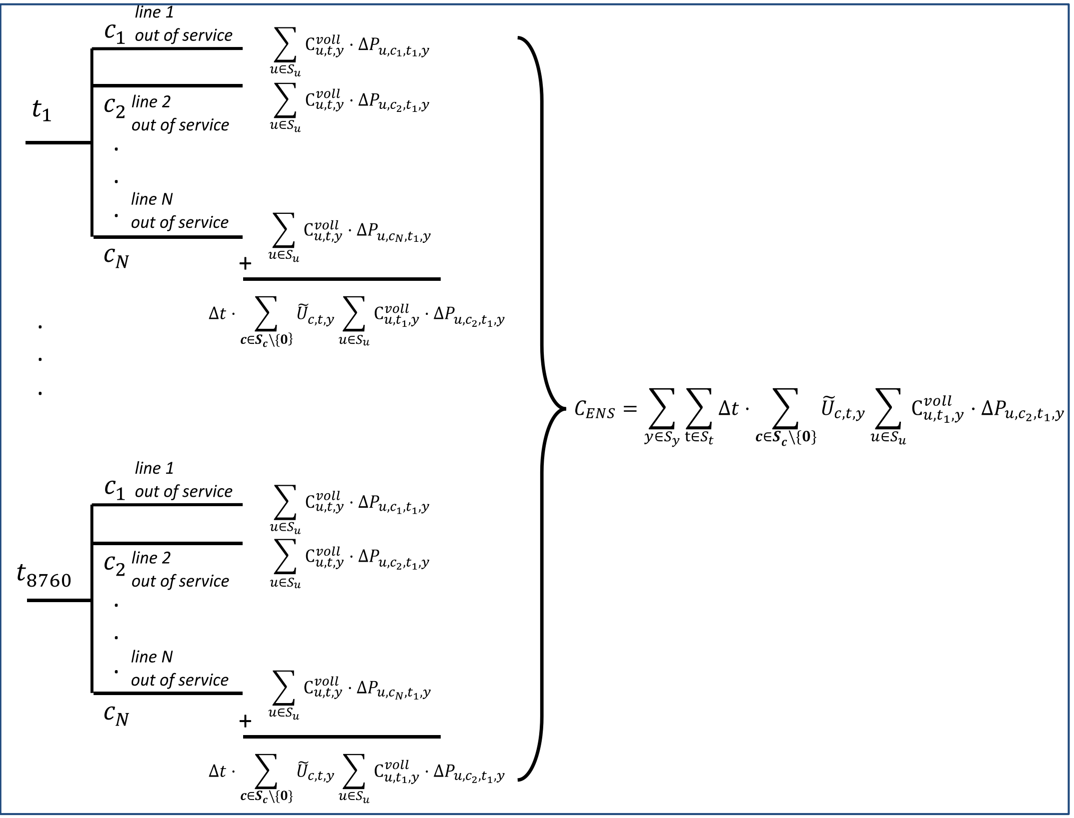
$$f_y^{d,i} = \frac{1}{(1+r^d)^{y-\tilde{y}}}$$

Discount factor for the residual investment value:

$$f_{y_{end}}^{d,i} = \frac{1}{(1+r^d)^{y_{end}-\tilde{y}}}$$

y_{end} is the expected end-of-life year for investment j

Reliability modelling and analysis of grid contingencies



The reliability impact of the chosen grid expansion candidates is added to the objective function as an additional cost of energy not served C_{ENS}.

Considering a number of critical contingencies, $c \in S_c = \{c_1, \ldots, c_n\}$, the cost related to power curtailment due to a contingency ($\Delta P_{u,c,t,y}$) is calculated for each demand unit using the relevant value of lost load ($C^{voll}_{u,t,y}$).

These costs are summed up over all demand units $u \in S_u$, each time point $t \in S_t$, each planning year $y \in S_y$ and each contingency $c \in S_c$ and is weighed with the contingency probability $\tilde{U}_{c,y,t}$ which is determined by using failure rate and mean time to repair (MTTR) of the specific equipment and multiplied by the duration of the contingency Δt.

Modeling of environmental factors

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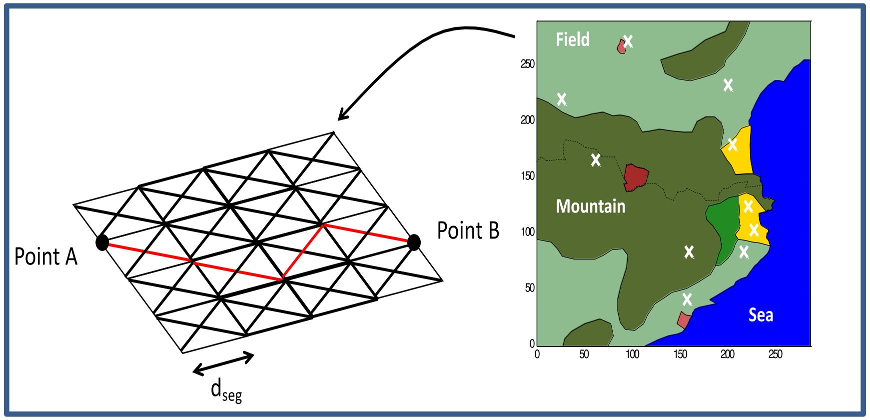
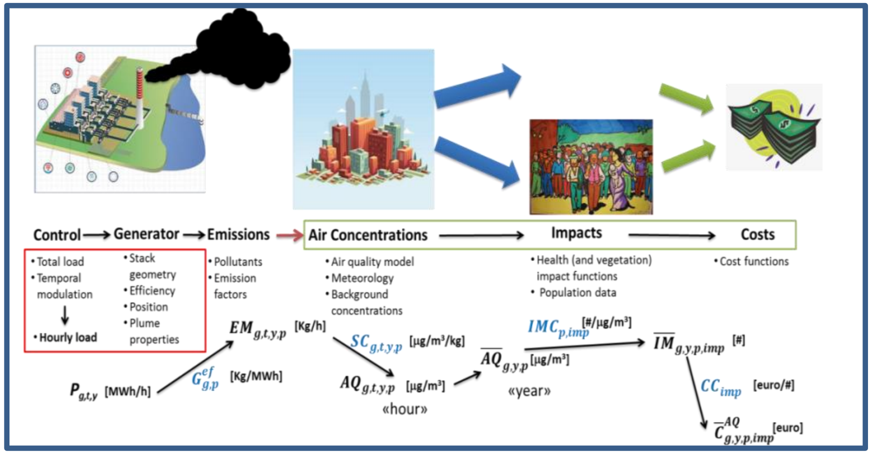
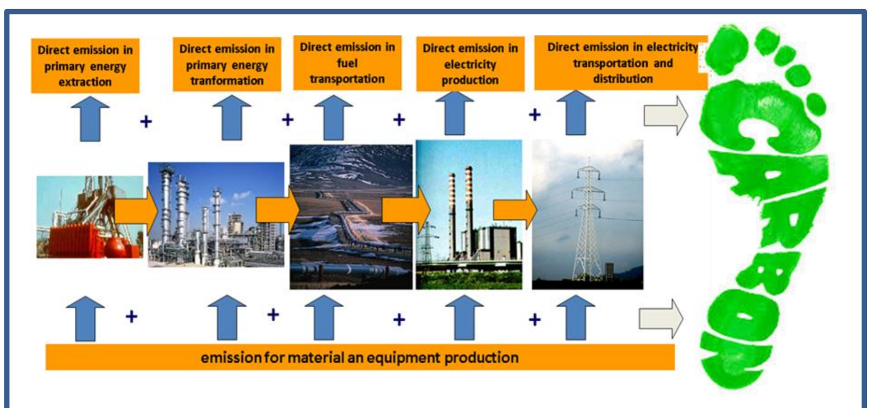


Landscape impact modelling



Air quality modelling



Carbon footprint modelling

Grids modeling

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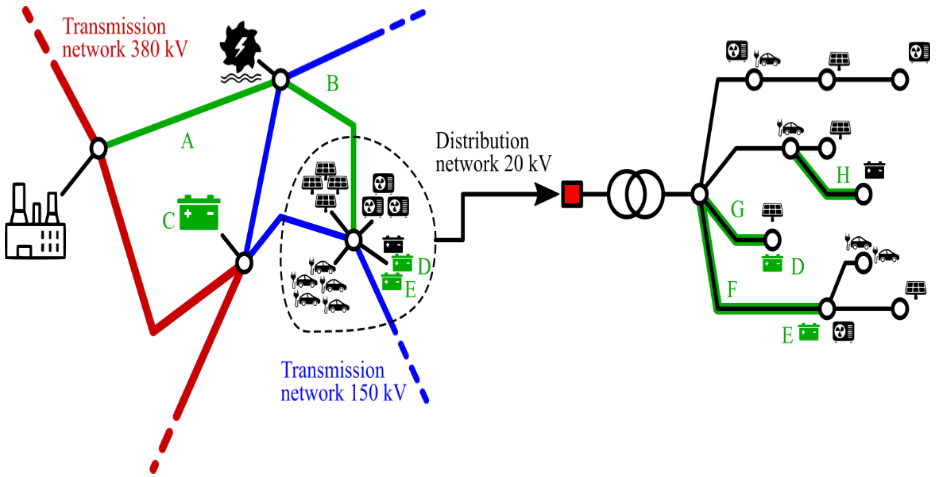


In order to maintain computational tractability, linearized models are adopted:

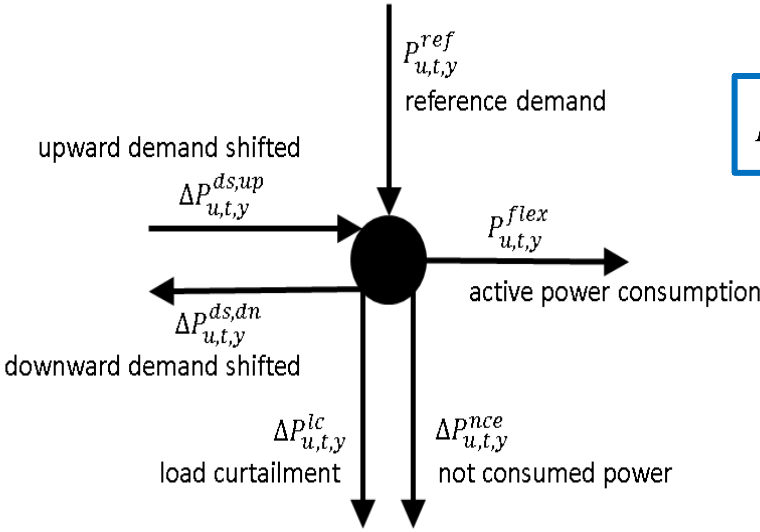
- DC approximation for transmission grids
- linearized approach (DISTFLOW-like) simplifying but not eliminating reactive power for distribution grids

Simulating real distribution networks in detail would result in a 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.

The T&D grid model is decomposed into two components: meshed and radially operated networks. As the modelling of all radially operated systems would result in an unmanageable problem size, a four-step decomposition approach is chosen:

- **STEP 1:** a least-cost expansion plan of the radial network is determined with the objective of solving only local congestion in the most economical way
- **STEP 2:** a highest-cost expansion plan of the radial network is performed with the objective of providing the maximum amount of flexibility in terms of delivering and absorbing active power to/from the meshed network
- **STEP 3:** (optional) intermediate cases are analysed
- **STEP 4:** the radial grid expansion options of steps 1-2-3 are provided as expansion candidates for the meshed system, solved independently. The best trade-off is determined.

Flexible load modeling



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

Voluntary reduction of demand (nce = not consumed energy)

Upwards and downwards demand shifting

Involuntary reduction of demand (lc = load curtailment)

$$0 \leq \sum_{t \in S_t} \Delta t \cdot \Delta P^{nce}_{u,t,y} \leq \alpha_u E^{nc,max}_{u,y}$$

nce boundaries

$$\sum_{t \in \tau} \Delta P^{ds,up}_{u,t,y} = \sum_{t \in \tau} \Delta P^{ds,down}_{u,t,y}$$

Same shift in both directions

$$0 \leq \Delta P^{ds,up}_{u,t,y} \leq \Delta^{ds,up,max}_{u,t,y} - \sum_{\tau \in \left\{t-\tau^{ds,up,grace}_{u,y},\dots,t-1\right\}} \Delta P^{ds,up}_{u,\tau,y}$$

$$0 \leq \Delta P^{ds,dn}_{u,t,y} \leq \Delta^{ds,dn,max}_{u,t,y} - \sum_{\tau \in \left\{t-\tau^{ds,dn,grace}_{u,y},\dots,t-1\right\}} \Delta P^{ds,dn}_{u,\tau,y}$$

Maximum demand shifting

Storage modeling

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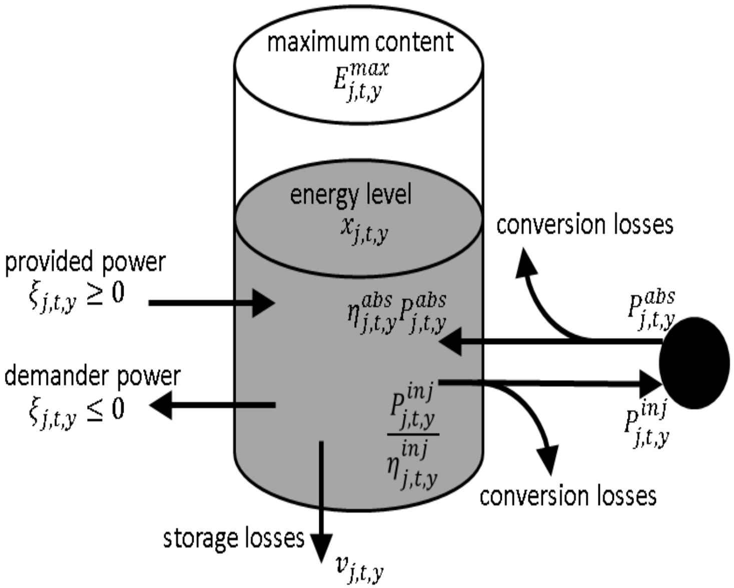


Energy stored at time t

Energy stored at time t-Δt

$$E^{max}_{j,y} x_{j,t,y} = E^{max}_{j,y} x_{j,t-\Delta t,y} + \Delta t \cdot \left(\eta^{abs}_{j,y} P^{abs}_{j,t,y} - \frac{P^{inj}_{j,t,y}}{\eta^{inj}_{j,y}} + \xi_{j,t,y} - v_{j,t,y} \right)$$

Energy absorbed from network at time t

Energy injected into network at time t

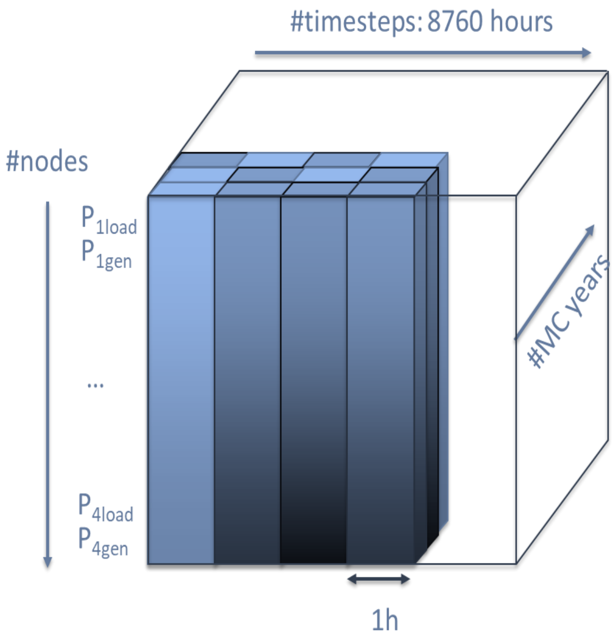
Exogenous terms

$$E^{min}_{jc,y} \alpha_j \leq E^{max}_{jc,y} x_{jc,t,y} \leq E^{max}_{jc,y} \alpha_{j,y}$$ Boundaries to per unit load state *x*

$$0 \leq P^{abs}_{jc,t,y} \leq \alpha_{j,y} P^{abs,max}_{jc,y}$$ Boundaries power absorbed from network

$$0 \leq P^{inj}_{jc,t,y} \leq \alpha_{j,y} P^{inj,max}_{jc,y}$$ Boundaries power injected into network

Monte Carlo approach



Yearly climate variants (variability of RES time series and load time series) for each of the grid years are taken into account in the framework of a Monte Carlo process.

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

The adoption of a Monte Carlo approach presents 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.

Methods based on stochastic modeling (alternative to the Monte Carlo approach) don't allow to parallelize the runs and would be too heavy computationally.

This problem is solved by resorting to 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 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).

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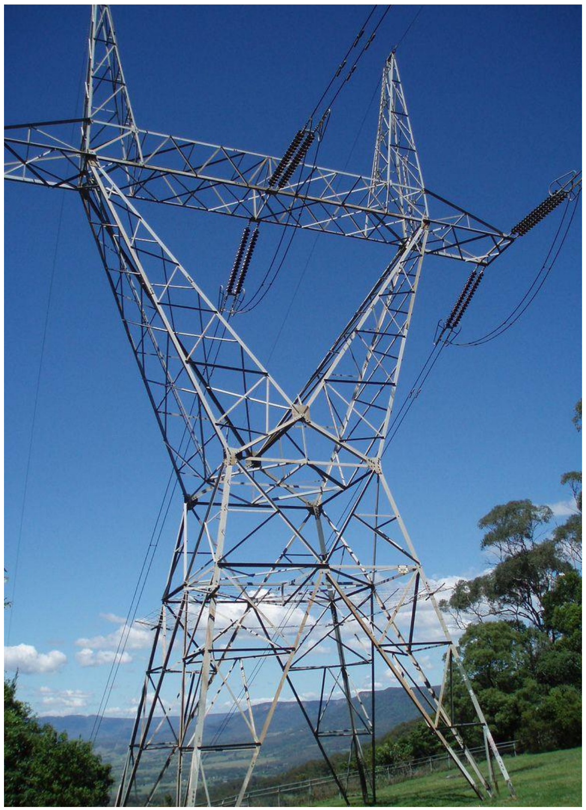
A “corridor expansion” approach



- 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**”.

- We suppose **the influence of nodal injections on line transits can be described by means of PTDF factors and that such factors don’t change in the surroundings of the starting point.**

- We use them to calculate parameter $\gamma_{L,LC}$ saying, for each line L how much oversaturated is LC when L becomes saturated. **If we order all lines L by their $\gamma_{L,LC}$ factor, the lowest ranked will be those lines which become saturated first when the line LC increases its capacity and so, they should be clustered with it.**

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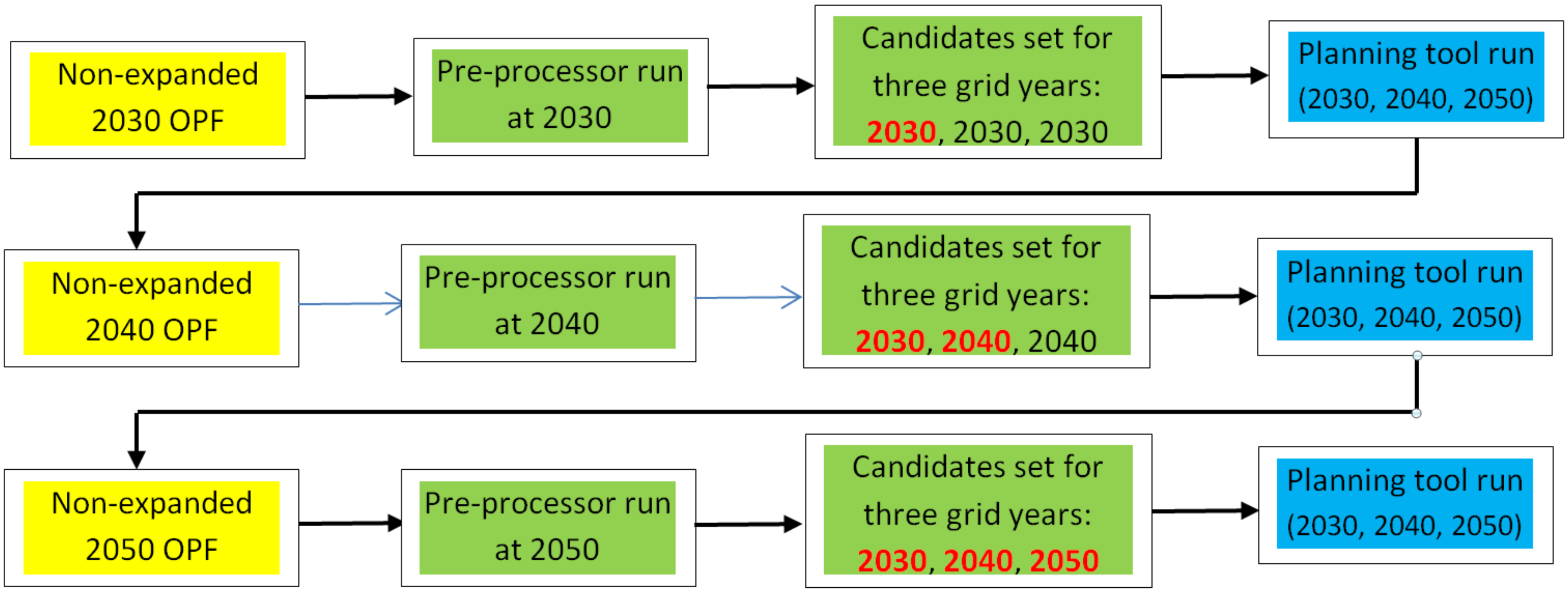
Interaction between pre-processor and planning tool



Pan-European and regional scenarios generation

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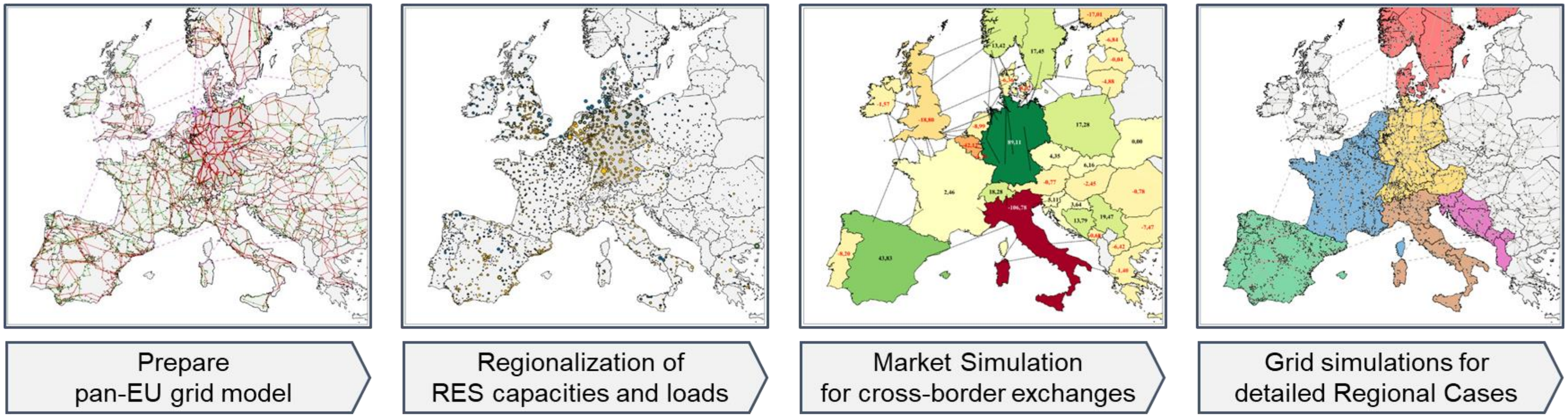

The main source for the scenarios considered in FlexPlan project is the Ten Year Network Development Plan (TYNDP) 2020, developed by ENTSO-E, which describes possible trends up to 2050. ENTSO-E's TYNDP describes three scenarios:

- National trends
- Distributed Energy
- Global Ambition

that added up over three grid years (2030, 2040, 2050) makes up 9 scenarios to be considered by FlexPlan. For 2050, the document "A Clean Planet for all" by the EC was also considered.

ENTSO-E's TYNDP 2018 pan-European **transmission grid model** (extra-high voltage) is also utilized as a basis for the FlexPlan simulations. For sub-transmission, public data from Open Street Map sources is used alongside with information available to the consortium partners.
Synthetic distribution networks are created in order to have a reduced scale model of the real networks. They are created on the basis of network statistics.

Some preliminary ideas for the planning guidelines

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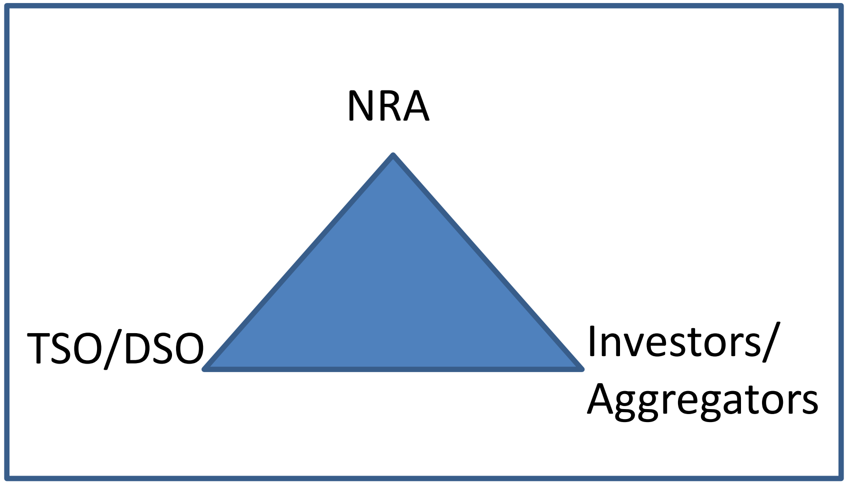

Investments in storage and flexibility will remain mostly in the hands of private investors. **National Regulatory Authorities should translate the suitability of deploying new storage or flexibility in strategic network locations into opportune incentivization to potential investors.** This complicates the traditional scheme, where System Operators after carrying out planning analyses were the only subject entitled to invest.

In alternative, **NRAs could charge SOs to set up calls for bids for investing in promising nodes.**

Final possibility is that **strategic locations can be managed with storage devices directly installed by the SOs, provided that, given the natural monopoly position of them, they are managed in a non-profit-oriented way**, similarly to must-run power plants (Art. 54-1(b) of Directive of the European Parliament and of the Council on common rules for the internal market in electricity: "*Member States may allow transmission system operators to own, develop, manage or operate energy storage facilities… if such facilities or non-frequency ancillary services are necessary for the transmission system operators to fulfill their obligations under this Directive for the efficient, reliable and secure operation of the transmission system and they are not used to buy or sell electricity in the electricity markets*").

Once investments are carried out, the real time markets dealing with grid congestion should be able to:

- **reflect the real situation (nodal markets are essential for that)**
- **provide optimal locational signals orienting aggregators' bidding the network**
- **define the products so as not to create entry barriers and not to discriminate any potential flexibility provider.**

The FlexPlan web

- The official web site of the FlexPlan project is: https://flexplan-project.eu/ All project news and other information are posted there
- Project brochure can be downloaded from: https://flexplan-project.eu/wp-content/uploads/2020/02/FlexPlan_brochure.pdf
- All project publications (deliverables, papers, important presentations) are publicly downloadable from: https://flexplan-project.eu/publications/

Questions by ENTSO-E (1/4)

- Which flexibility elements/non-wire alternatives do you take into account? What does flexibility mean in your project (which needs/services)?

  - The service addressed by FlexPlan is **congestion management**

  - **The time granularity (hourly) doesn’t allow to consider faster services** (like frequency regulation or balancing)

  - Considered **non-wire alternatives:**
    - **storage** elements (different types of technologies: batteries, CAES, hydrogen…) and
    - the transformation of big (industrial and tertiary) loads into **flexible loads** (i.e. suitable for voluntary and involuntary curtailment as well as load shifting)

Questions by ENTSO-E (2/4)

- Which voltages level does FlexPlan address? Do you have different approach to transmission and distribution grid?
  - **Voltages:** all transmission voltages: EHV (400kV + 220kV) and sub-transmission (150-130kV) + the highest voltage of the distribution networks (meant as: «radially exercised networks»)
  - **Transmission grid** (low R/X ratio) is represented by a typical direct current linearized model.
  - In **distribution grids** (high R/X ratio) reactive power cannot be fully disregarded: a DISTFLOW-like approach was adopted, simplifying reactive representation without neglecting it completely, yet keeping the model linear for numerical tractability.
  - **Synthetic distribution networks** are creating because managing the complexity of real distribution would be not mathematically manageable. Yet, such synthetic networks are created by using statistics on real networks.
  - **Benders' decomposition** and **T&D decoupling** should further contribute to maintain numerical tractability.

Questions by ENTSO-E (3/4)

- What are the main criteria that you take into account in your CBA? How do you assess the costs associated to each flexibility element (e.g. demand-side response)?
  - One of the key points of he FlexPlan approach is that **we don’t consider a separate CBA** with respect to the optimization: the target function of the OPF solved by the planning tool already represents the CBA. Such OPF evaluates candidates altogether (new lines/cables, new storage elements, flexible exercise of key loads) and determines the solution which minimizes the sum of OPEX (dispatching costs) and CAPEX (investment costs). Environmental externalities are translated into costs and included into the target function.
  - The **costs associated to flexibility elements are scenario values** and we are still thinking of the most objective methodology for setting them up.

- Are there any previous projects or national good practices that FlexPlan is based on? Do you know other organisations which are working on the issue and that you would advise us to reach out to?
  - **FlexPlan takes profit of the experience gathered in previous past projects** (REALISEGRID, e-Highway2050) but is not based on these projects.
  - There is **no present good practice** we base our work upon: our methodology is innovative and the result of an R&D activity.

Questions by ENTSO-E (4/4)

- Besides the planning tool, what are the expected outcomes of the project? What kind of recommendations do you foresee for NRAs and policy-makers?
  - Yet being an important product of the project, the planning tool is not the only outcome expected from it. Other important products will be:
    - the **pre-processor**, building up a complete toolkit with the planning tool, the pre-processor formulates the candidates upon which the planning tool takes investment decisions, so it's a delicate tool, necessarily also partially based on heuristics,
    - the results of the **scenario analyses on 2030-40-50** for the six regional cases, covering most of Europe, casting a view on the potential role of flexibility in the future,
    - the **planning guidelines** that will be elaborated during the final phase of the project by considering project outcome and present regulatory trends in Europe.

- **The entire planning + pre-processor suite, yet not public, could be put available for interested stakeholders after the end of the project upon conditions to be agreed with the Consortium.**
- **A "toy version" of the planning tool (non modifiable and on a close set of data) will be made freely available upon request.**
- **The JL library that is being used for the reduced-scale WP1 tests is subject to open source licence and will be put freely available with open access license.**

Thank you…

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