This project has received funding from the European Union's Horizon2020 research and innovation programme under grant agreement N° 863819

FlexPlan

Final Workshop | 14th February 2023

N-SIDE

The Grid Expansion Planning Software

Maxime Hanot
N-SIDE

Agenda

- About N-SIDE
- Planning engine:
  - architecture and design
  - development process
  - challenges and solutions
- GUI development process
- Live demonstration
- Next steps

N-SIDE, the advanced analytics partner for energy actors

Our mission

Enable the Energy Transition with innovative advanced analytics solutions

N-SIDE

Founded in 2000, university spin-off

Offices in **Belgium & US**

200+ people (Energy + LS)
30% PhD **37** Nationalities

42% annual growth

Our customers and partners

Market Participants

axpo, AGC, BritNed, centrica, SCHOLTenergy, EDF luminus

Power Exchanges

NORD POOL, GME, omie, HEnEx, IEX, epexspot

System Operators

Svenska Kraftnät, entsoe, Statnett, elia, 50hertz, nationalgridESO, swissgrid, fluxys

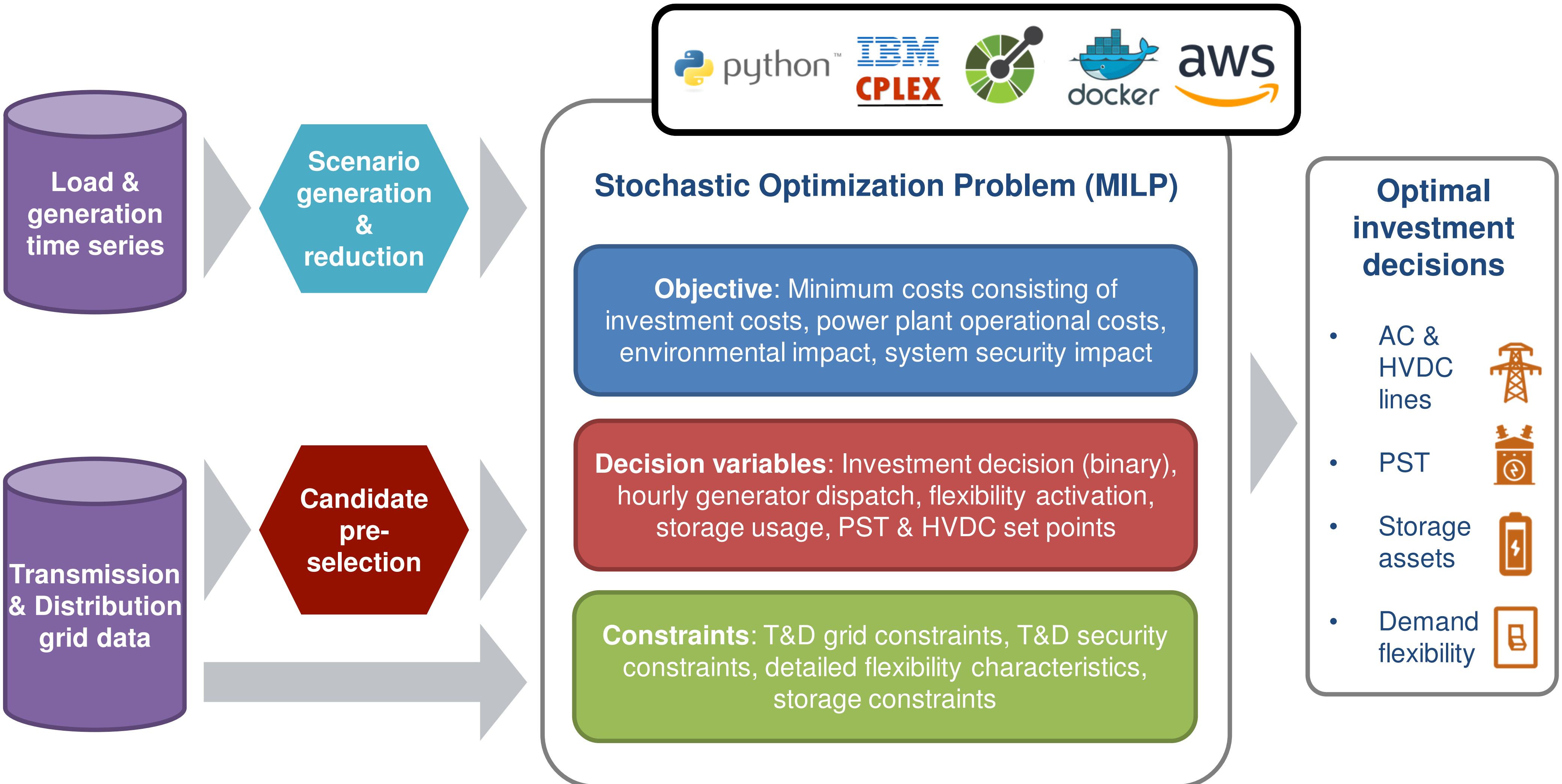
Our offering

- Forecasting Solutions
- Market Clearing Solutions
- Advanced Analytics for System Operation
- Advanced Analytics for Asset Management
- Innovative Market Design

Architecture & Design

N-SIDE FlexPlan

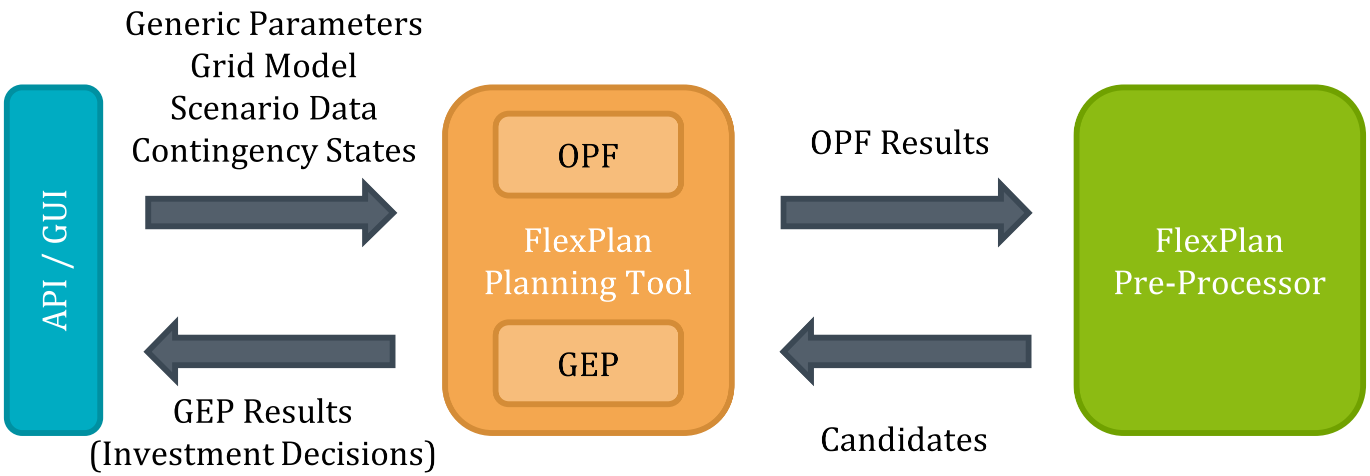
The FlexPlan planning tool is based on stochastic optimization and was developed using state-of-the-art technologies



Architecture & Design

N-SIDE FlexPlan

The FlexPlan planning tool implements a three-step methodology



Grid Model	•	The topology of the power system, providing static technical characteristics related to buses, lines, converters, transformers, loads, generators, and storage devices
	•	Similar to equipment profile (EQ) data files, used in CGMES by ENTSO-E
Future Scenarios (2030/2040/2050)	•	Time dependent data related to loads, generators, and storage devices
	•	Similar to the steady-state hypothesis (SSH) data files, used in CGMES by ENTSO-E
Optimal Power Flow Results	•	Outcomes of the non-expanded network for the years provided in input: Locational Marginal Prices (LMPs) at the buses, power flow directions in branches, and Lagrange Multipliers (LMs) associated with each branch.
Candidates	•	Characteristics of the investment candidates: resource location, type of flexibility technology candidate, alongside with its size and cost
Investment Decisions	•	List of the optimal investment decisions based on the provided candidates expressed as Boolean variables

Architecture & Design

N-SIDE FlexPlan

The FlexPlan planning tool can also be used to perform scenario reduction

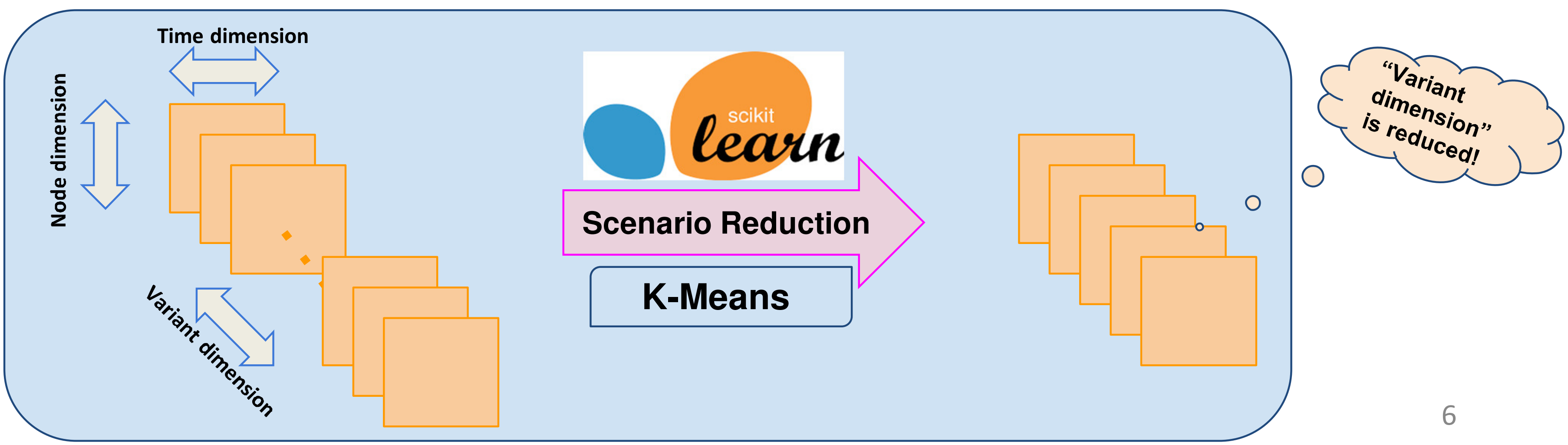
Scenario Reduction is performed with ***K-means*** clustering technique.

- Scenario data is **scaled** upfront!
- Scenario data of **'k' time-series** can be reduced to **'k*' time-series** for **each node**!

Scenario Features are extracted from the scenario data and used as primary features to perform the scenario reduction!

Scenario Reduction can also be performed with along the **time dimension**:

- Reduction to monthly, weekly or daily time series!



Architecture & Design

N-SIDE FlexPlan

Data privacy concerns leaded to the implementation of several security layers

Input handling — **The sensitive input data** is only kept during processing and not persisted to drives afterwards (only for the engine, not for the GUI)

IPWL — **IP whitelisting**, security feature used to **limit** and **control** the access to the tool to trused users

Authentication — **Basic authentication** , ensuring that each regional case has its own username and password, so their simulations can only be accessed by those who have those keys available

HTTPS — **Extension of HTTP protocol** commonly used for secure communication over a computer network (encryption during transfer)

Development Process: Approach

The optimization engine is composed by several individual building blocks, which were implemented in an agile way

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Web Consultation – Planning tool: Features and interfaces

The FlexPlan project aims at creating an innovative grid-planning tool considering the opportunity to introduce new storage and flexibility resources in electricity transmission and distribution grids as an alternative to network reinforcement.

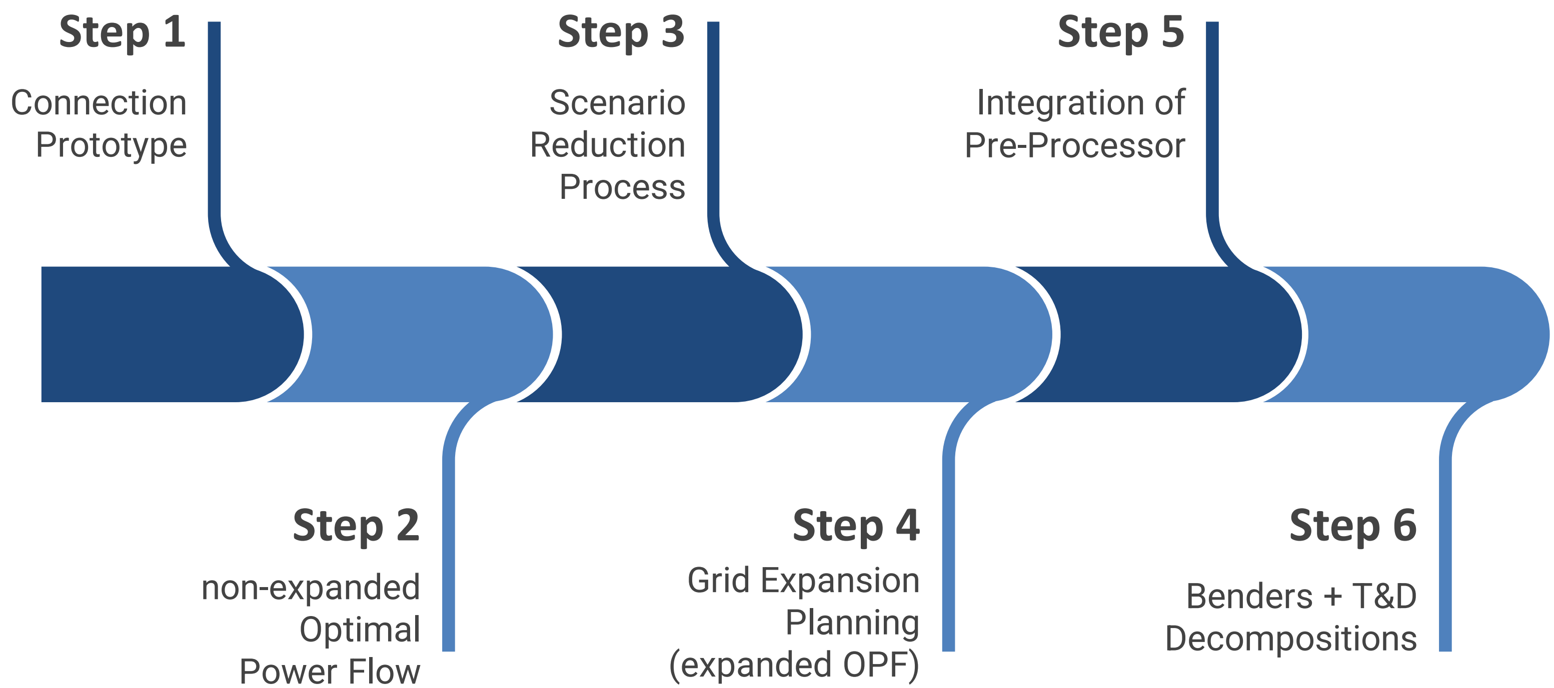
The following features will be considered and implemented in the new planning tool:

- **integrated T&D planning**: the idea is to consider both transmission and distribution (Medium Voltage level) grid planning and how they impact each other.
- inclusion of **environmental impacts**: carbon footprint, pollutants emission, landscape impact
- **probabilistic reliability methods** (as an alternative to N-1 criterion), considering the probabilities (and costs) of failures.
- **dynamic planning**: multiple time horizons for the investments are considered and linked together (i.e., investments at various time horizons will be considered as well as their impact on decisions in subsequent time horizons).
- **modelling of storage** and **flexibility** from demand response as alternative to network reinforcement (see also Web Consultation - Technology: flexibility resources)
- **Monte Carlo simulations** to tackle the **uncertainty** and reduction techniques to limit the number of scenarios. The uncertainty may be about **investments parameters** (e.g., storage technology cost in 2050, discount rate), or also about **operational uncertainties:** weather (temperature), RES production, load, fuel costs, network element failures probabilities).

Questions: Your current planning tool and process

- Please describe the current planning tool which you are using
  - Frequency of use (daily, weekly, yearly)
  - Planning horizon considered for the planning (e.g., 5 years, 10 years)
  - Main user of the tool (e.g., analyst of grid planning department)
  - Graphical user interface (Yes/no)
  - Integrated with other systems (e.g., SCADA, AMI)
  - Vendor or in-house development
  - Types of analysis performed (Load Flow, Probabilistic Load Flow, OPF, etc.)
- In your current planning tool/methodology, what are the features that you lack (the most)?
- Which other (modelling) features should be considered in the planning tool in your opinion?

Many input data are needed to "feed" the planning model (i.e., values for the parameters of the model), according to a data model structure. Data intrinsically come from scenarios since the planning tool considers the future (for FlexPlan: 2030, 2040 and 2050 are the investment time horizons which are considered in the regional cases). While the scenario aspect is discussed in another Consultation (see Web Consultation - 2050 Scenario Data), we want to consider data models which would make easy/possible to test it on real instances after the end of the project.



Development Process: Testing

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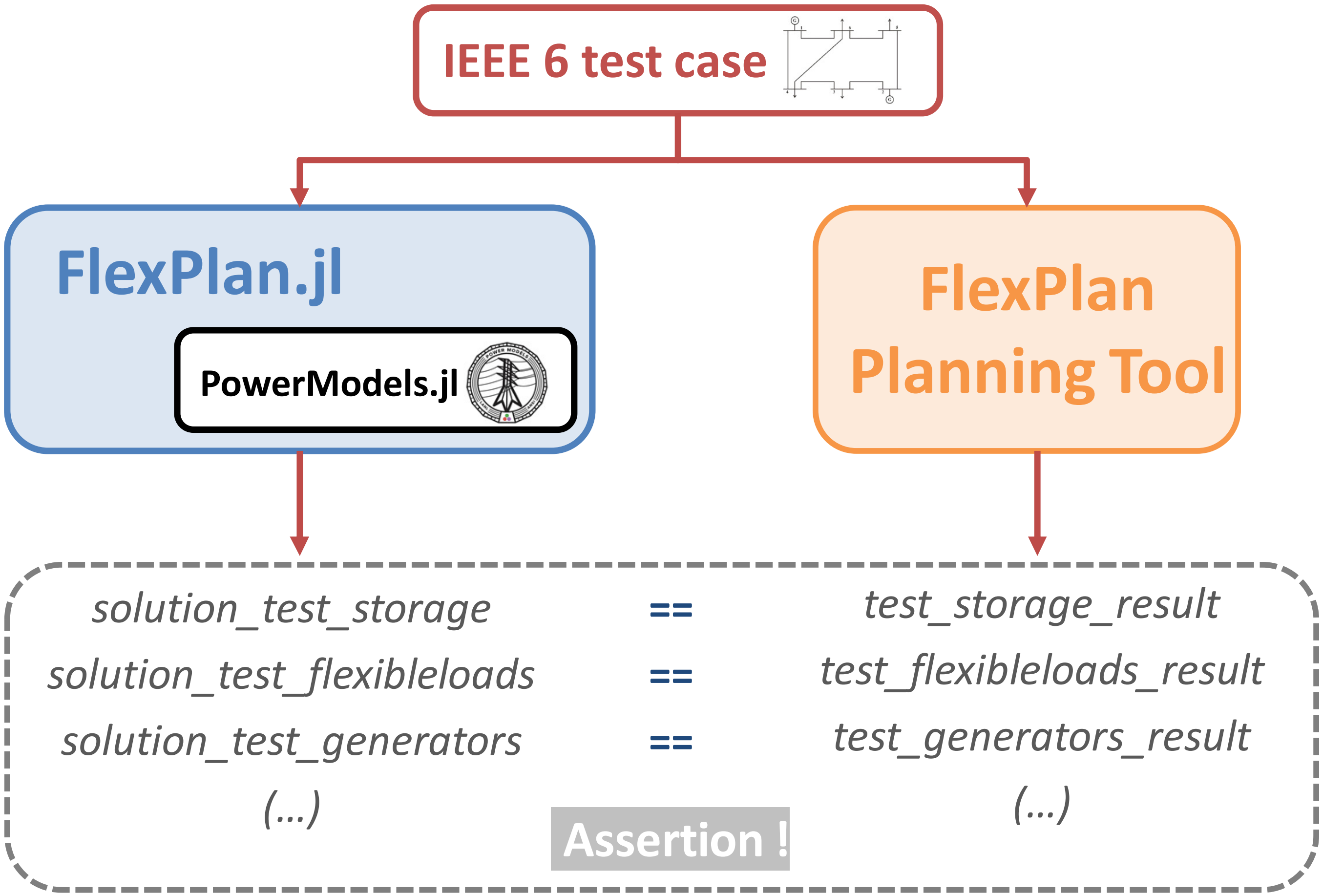
Correctness testing was mainly done by comparing results with the open-source software on a small test case. Integration and performance testing were also executed.



Implementation Challenges

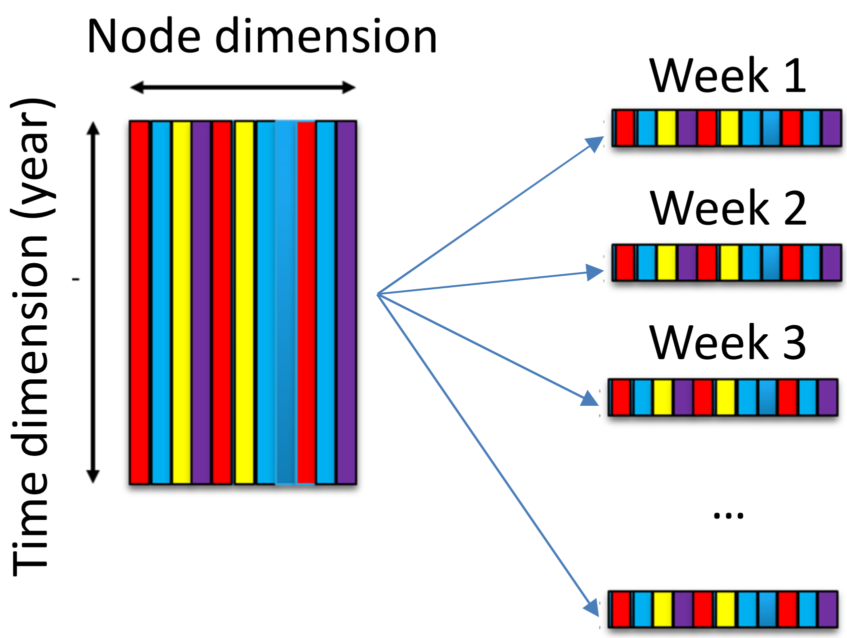
The problem to be solved is a large-scale Mixed Integer Linear Program, requiring a lot of memory and computing power to be solved

Implementation ~~Challenges~~ Solutions!

N-SIDE FlexPlan

Those challenges forced us to fine-tune our algorithm and to assess and implement several simplifications while not jeopardizing the quality of the solutions.

- *Coupling of time periods considered with two-hour blocks*
- *Selection of representative weeks to consider the variability of load and RES time series*

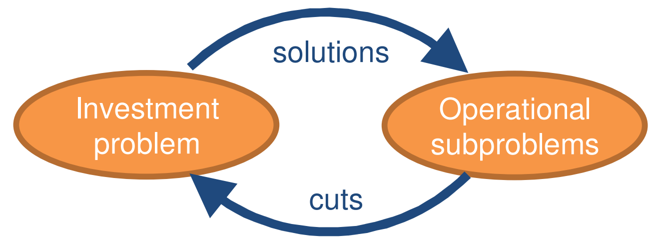


CPLEX parameters tuning to select most efficient methods for our problems

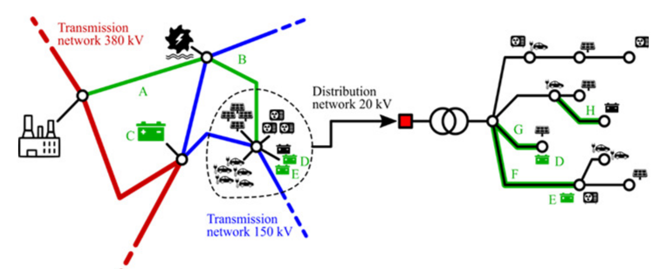
Default **> 12 hours** → Tuned **< 2 hours**

Decomposition methods to reduce solve time:

- *Benders (exact method to decompose the investment and operational problems)*



- *T&D (innovative method to decompose transmission and distribution problems)*



GUI Design & Implementation Process

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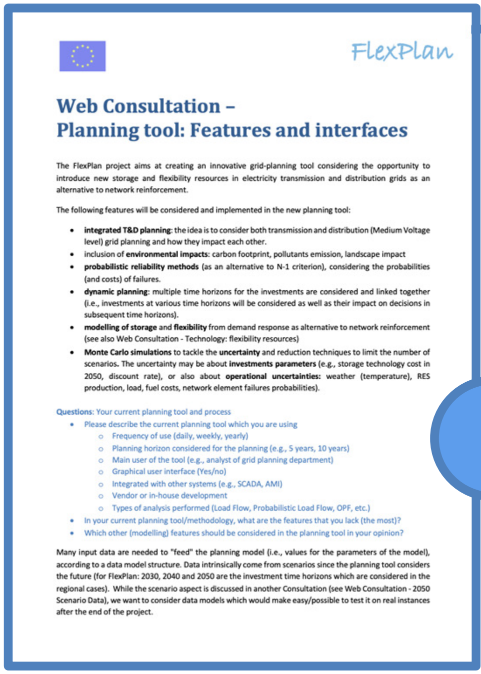
Building up a Graphical User Interface is a rigorous, methodological and iterative process



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Web Consultation –
Planning tool: Features and interfaces

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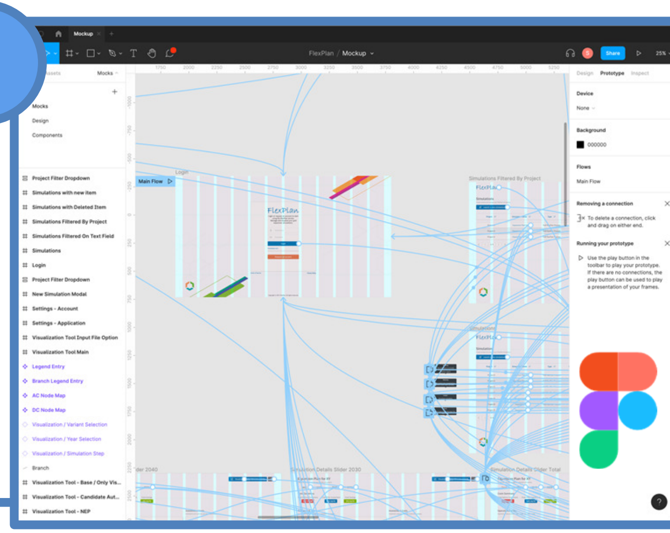
1

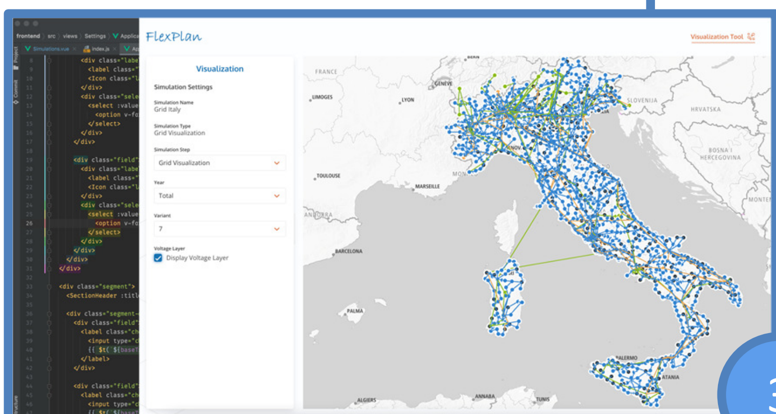
Requirements identification: collect the feedback/opinion of potential users through customer consultation surveys

2

UI/UX design: define technologies, features and interactions between the screens using user flows, wireframes, mock-ups and prototypes



3



Implementation: develop all screens and features, including the link with the planning engine

django Vue.js

4

Documentation: write the user manual for the GUI and planning engine usage

FlexPlan

Advanced methodology and tools taking advantage of storage and FLEXibility in transmission and distribution grid PLANning

Planning tool user documentation

D3.2

Distribution Level	PU
Responsible Partner	N-SIDE
Checked by WP leader	Hanot Maxime (N-SIDE) – WP3 Leader Date: 25/10/2022
Approved by Project Coordinator	Gianluigi Migliavacca (RSE) Date: 26/10/2022

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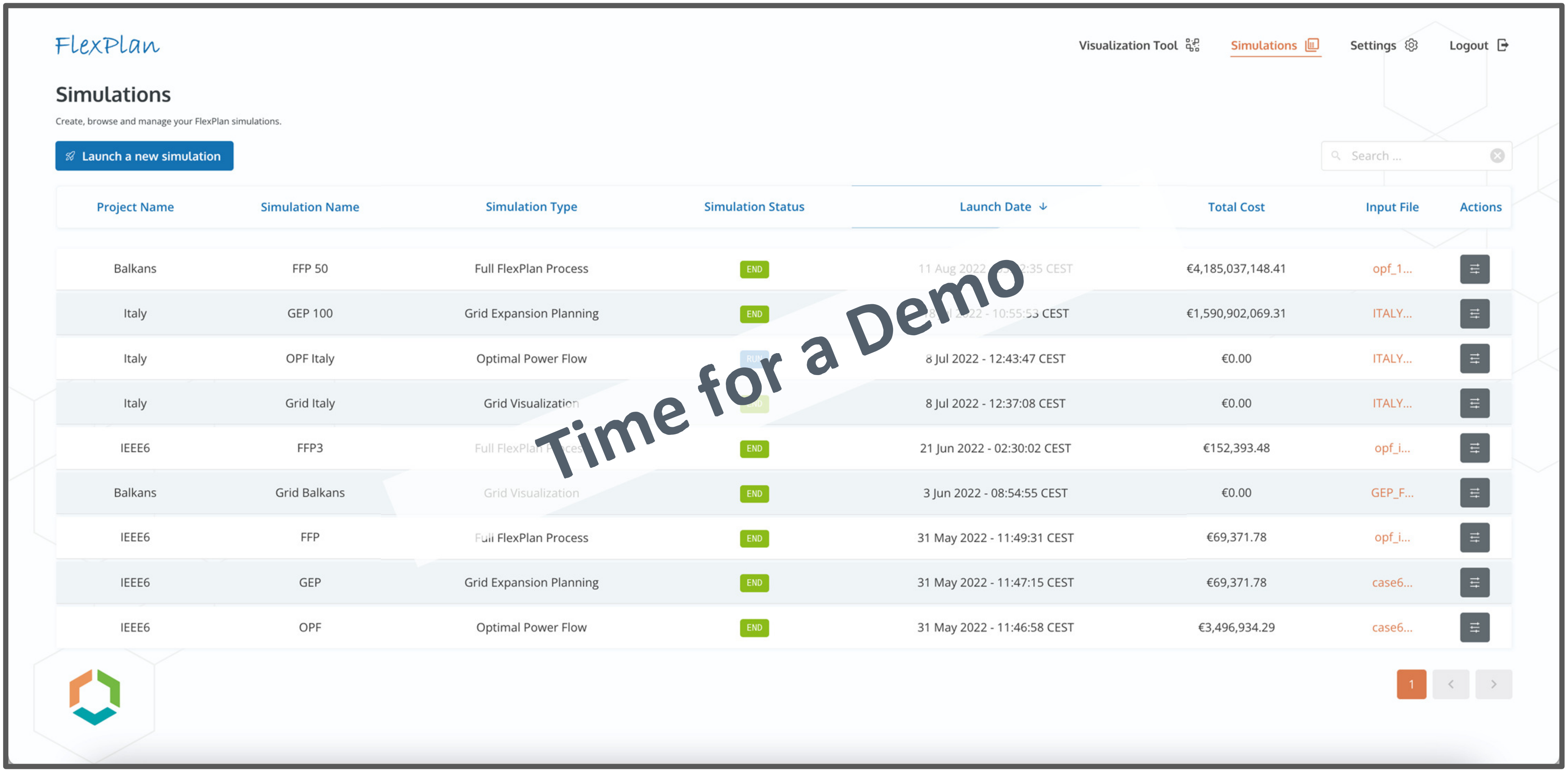

Project Name	Simulation Name	Simulation Type	Simulation Status	Launch Date	Total Cost	Input File	Actions
Balkans	FFP 50	Full FlexPlan Process	END	11 Aug 2022 - [illegible]2:35 CEST	€4,185,037,148.41	opf_1...	
Italy	GEP 100	Grid Expansion Planning	END	[illegible] 2022 - 10:55:53 CEST	€1,590,902,069.31	ITALY...	
Italy	OPF Italy	Optimal Power Flow	[illegible]	8 Jul 2022 - 12:43:47 CEST	€0.00	ITALY...	
Italy	Grid Italy	Grid Visualization	[illegible]	8 Jul 2022 - 12:37:08 CEST	€0.00	ITALY...	
IEEE6	FFP3	Full FlexPlan Process	END	21 Jun 2022 - 02:30:02 CEST	€152,393.48	opf_i...	
Balkans	Grid Balkans	Grid Visualization	END	3 Jun 2022 - 08:54:55 CEST	€0.00	GEP_F...	
IEEE6	FFP	Full FlexPlan Process	END	31 May 2022 - 11:49:31 CEST	€69,371.78	opf_i...	
IEEE6	GEP	Grid Expansion Planning	END	31 May 2022 - 11:47:15 CEST	€69,371.78	case6...	
IEEE6	OPF	Optimal Power Flow	END	31 May 2022 - 11:46:58 CEST	€3,496,934.29	case6...	

What's next?
The FlexPlan product roadmap

N-SIDE FlexPlan

Demonstrator finalized

Deployement for at least 2 SOs

2020 | 2021 | 2022 | 2023 | 2024

Feature set

- OPF and grid expansion planning problems
- Stochastic modelling considering variability of load and RES
- Storage and demand flexibility modeling (incl. coupling of hours)
- Customizable objective function including CAPEX and OPEX
- Benders and T&D decomposition
- Scenario reduction

- Enhanced contingency analysis
- Fast what-if analysis
- Solve performance review

- Early adopters program

Integration

- Configurable API connection
- Custom data model
- SaaS deployment capabilities
- Graphical User Interface

- CGMES 3.0 data model support
- On premise deployment option
- GUI enhancements
- Robustification (e.g. fallback)

Now

You want to know more?

FlexPlan public deliverables at https://flexplan-project.eu/publications/

- **D3.1.** Planning tool software, including GUI
- **D3.2.** Planning tool user documentation
- **D3.3.** Demo version of the planning tool

Contact us at flexplan@n-side.com for a demo or a trial

Follow us on

N-SIDE Energy

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Thank you…

Maxime Hanot

N-SIDE

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FlexPlan

Final Workshop | 14th February 2023

Pre-processor and planning candidates formulation

Santiago García

TECNALIA

Agenda

1. Aim of the pre-processor
2. Methodology summary
3. Methodology steps
4. Pre-processor interfacing
5. Validation
6. Conclusions
7. Reference documents

1. Aim of the pre-processor

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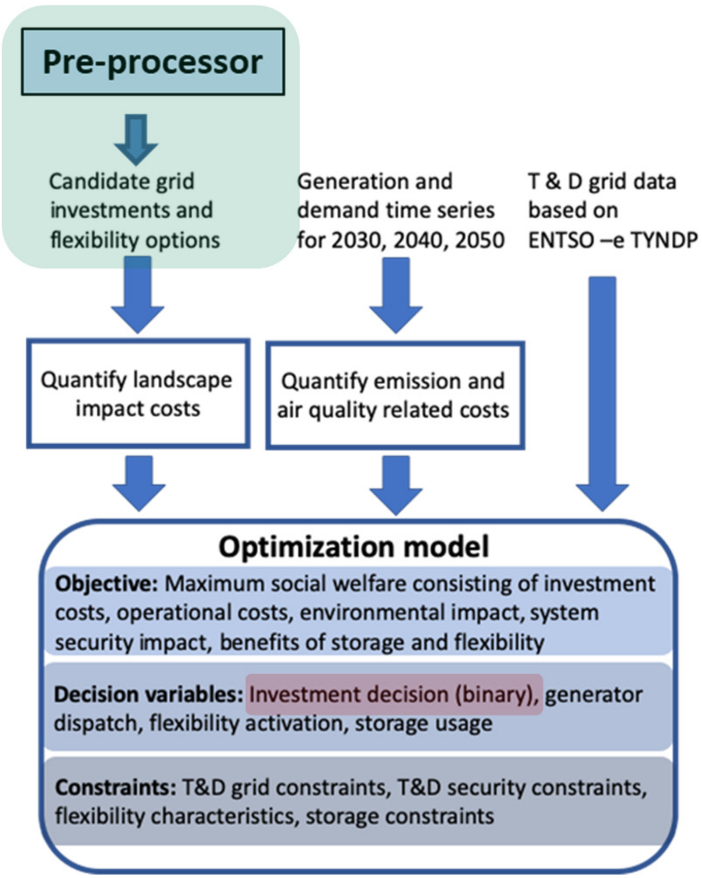


MOTIVATION

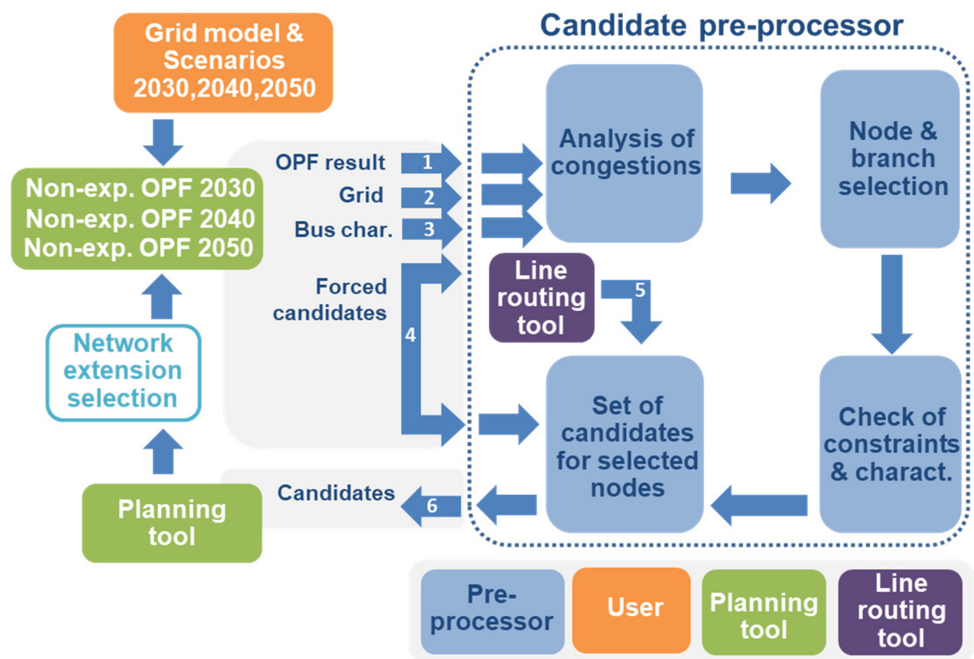
- **Small size flexibility resources**, as storage and demand, need to be part of network planning procedures.
- This increases the **complexity of the optimization problem**, causing a high computational burden.

OBJECTIVES

- Provide the FlexPlan planning tool with a **reduced list of network locations and technology candidates** for network extension.
- Flexibility resources are presented as candidates for network planning, **competing with the conventional** network capacity extension assets, e.g., new lines and transformers.

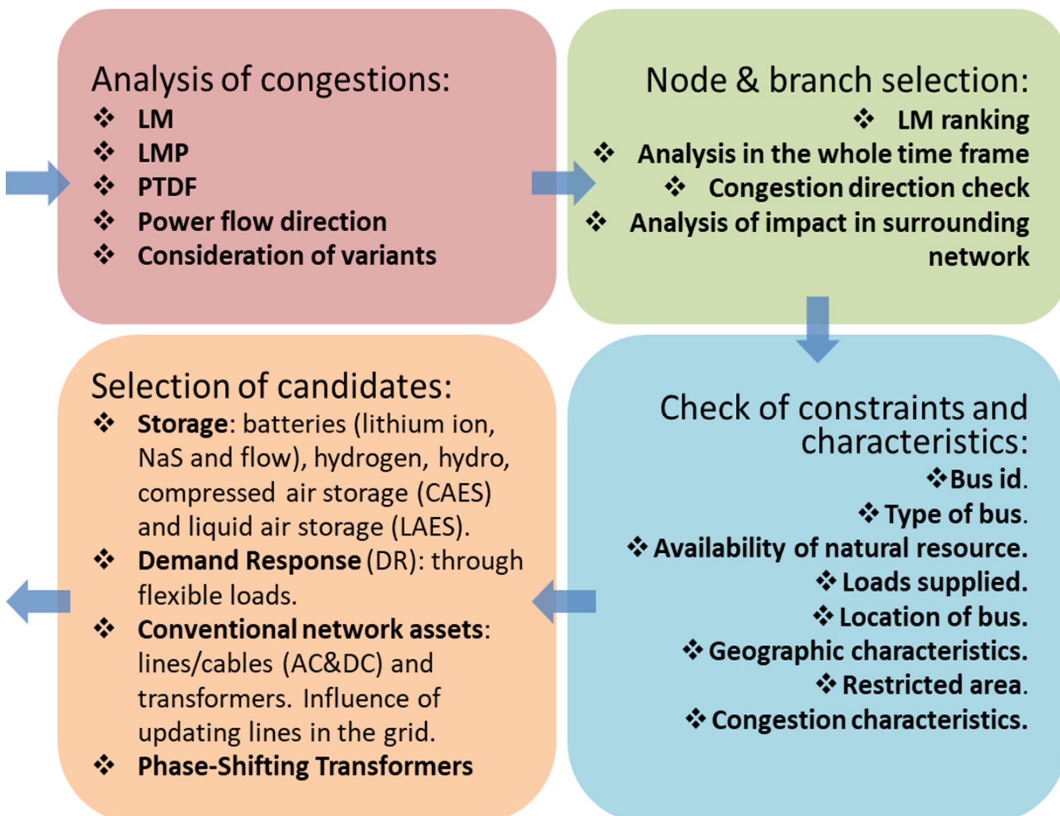
METHODOLOGY IN RELATION TO THE PLANNING

- The planning tool suite calculates an Optimal Power Flow (OPF) for the first decade under study (2030).
- The results of the OPF are used by the pre-processor to propose a set of candidates for network extension.
- The user could include other candidates manually.
- The planning tool solves the Grid Extension Problem (GEP) and selects or discards candidates among the proposed.
- Selected candidates are included in the network for the next decade (2040) and a new OPF is run.
- This is performed for 2050 in the same way.



3. Pre-processor methodology steps (I)

FlexPlan



PRE-PROCESSOR METHODOLOGY

- **Analysis of congestions**: the results of an OPF are the input to identify congestions in the network (T&D): Lagrange Multipliers (LM), Locational Marginal Prices (LMP), Power Transfer Distribution Factors (PTDF), power flows through branches, etc.
- **Node & Branch selection**: Depending on the characteristics of the congestion (severity, occurrence, duration) of lines, these are ranked.
- **Check of constraints**: the characteristics of congestions and of the constraints of the location are checked for each congested asset.
- **Selection of candidates**: location, technology, size and cost are proposed to the planning tool for each candidate for network expansion.

3. Pre-processor methodology steps (II)

CANDIDATE TECHNOLOGIES

- **Technologies** such as batteries (Li-ion, NaS and flow), hydrogen, CAES and LAES (compressed and liquid air storage) are eligible, depending on the characteristics of congestions and restrictions of the location.

OTHER TO BE INCLUDED MANUALLY

- Because they are very project-specific **other candidate technologies** can be proposed only by users: HVDC, Phase-Shifting Transformers (PST) and pumped-hydro.

Technology		Bus related characteristics and constraints																
		Type of bus				Resources		Location of bus					Total Restriction (1)	Congestion duration (5)				
		Substation		Load	Power Plant	no water	no cavern	urban	industry	semi-rural	Rural			Hours				Yearly
		air	under								Plain	Mount.		<2	2-6	6-24	>24	>4380 h
Batteries	Li-ion			(2)	(2)													
	NaS			(2)	(2)													
	Flow			(2)	(2)													
Demand Response	Total (aggregated per zones)	(3)	(3)	(4)				(3)	(3)	(3)	(3)	(3)						
	Industrial (per facility)	(3)	(3)	(4)				(3)	(3)	(3)	(3)	(3)						
Hydrogen				(2)	(2)													
Compressed air storage																		
Liquid-Air Electricity Storage systems																		
PST																		
Lines	AC overhead																	
	AC underground (cable)																	
	HVDC																	
Transformer, converter																		

(1) Restriction to build new facilities. It could be total or partial for certain technology (such as batteries, hydrogen, lines or substation)
(2) When the bus is specific of loads and/or generators, the decision to install storage should be of the owners of the plant and not of the regulator. SOs set connection conditions and third parties decide how to meet them.
(3) Loads connected to substations can be of different types: mostly residential, mostly commercial, mostly industrial, big industrial (specific big facilities), mixed
(4) Industrial loads can be of different types, e.g.: metal, paper, textile, cement, water treatment, gas industry, mining, shipyard, high speed train, automotive, chemical, hydrogen, other.
(5) Congestion duration could be considered as: average duration in hours of congestion, maximum duration of congestion, % of hours of congestion in a day…

3. Pre-processor methodology steps (III)

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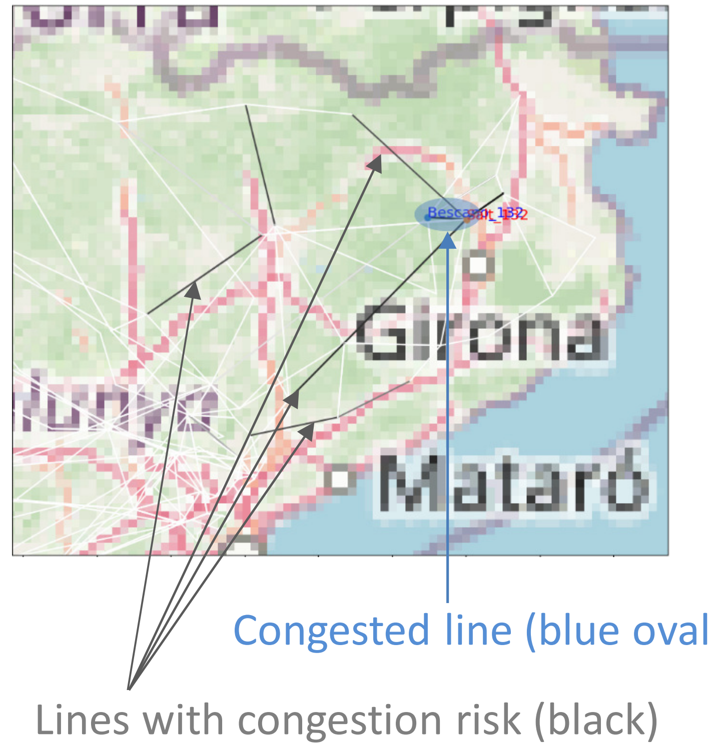
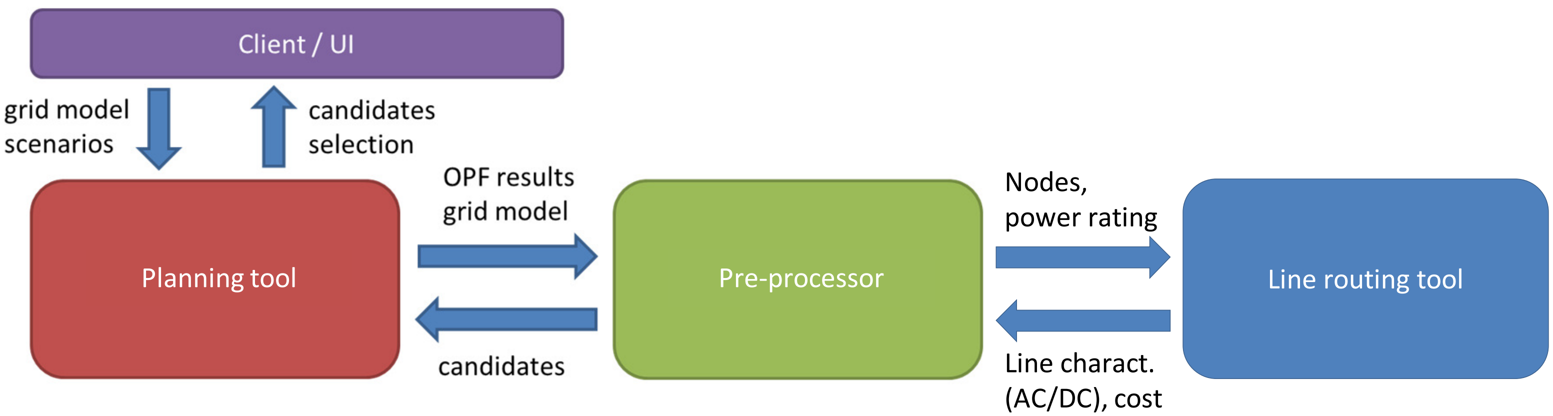
BRANCHES – CORRIDORS

- **In meshed networks,** solving a congestion in one branch may cause others to become congested in its surroundings.
- The Power Transfer Distribution Factors (PTDF) matrix is used to check how the increase o capacity in one line may affect the saturation of others.
- The risk of saturation is estimated through a parameter.
- When one congested branch or transformer is selected by the pre-processor (because ranked high), this parameter is evaluated for all lines in the network and those with highest congestion risk are also included in the candidate list.



4. Pre-processor interfacing

FlexPlan



- The user deals only with the planning tool, the pre-processor behaves in a “transparent” way.
- The pre-processor is hosted as **Docker image** in server of the planning tool.

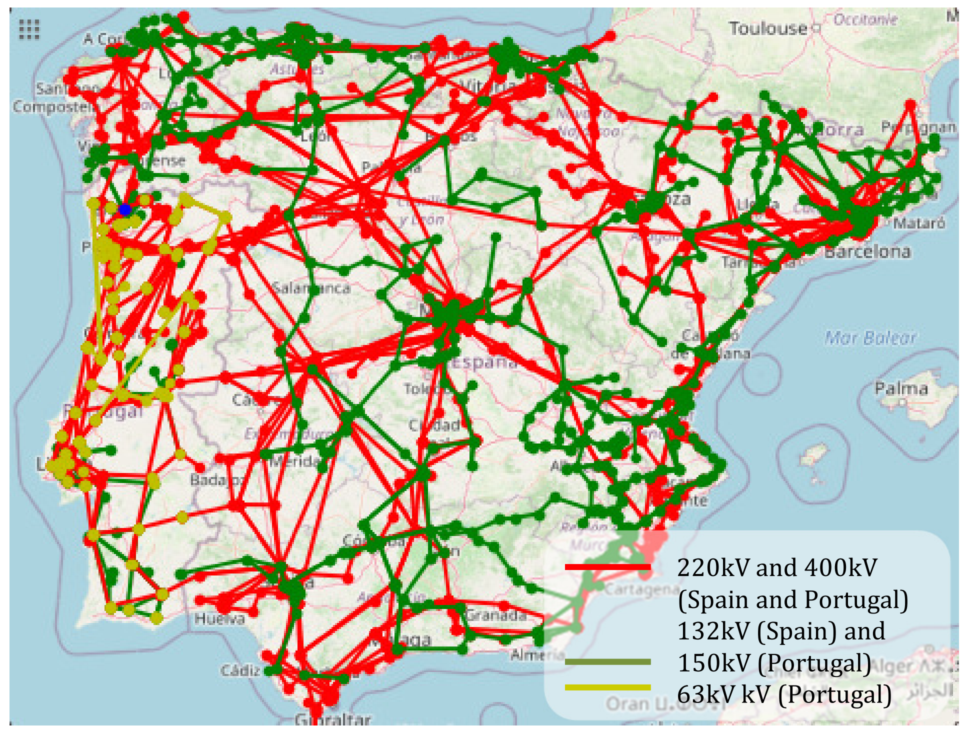
5. Validation (I)

FlexPlan

VALIDATION

- The validation and tuning of the pre-processor has been performed by the **Regional Case** leaders, when the planning procedure has been tested and the first results obtained.
- The results shown here are focused on the validation process of the **Iberian case**, including the networks of Portugal and Spain.

(the considered case is not the final one from which final results were obtained).

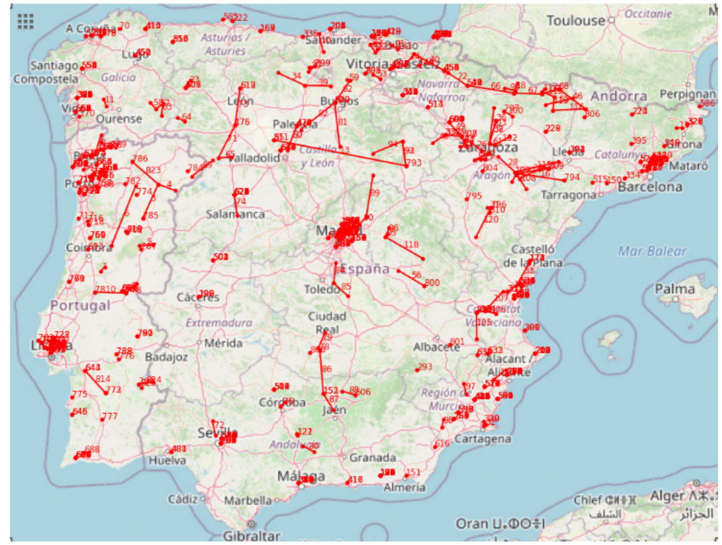


Modelled electricity network in RC Iberia

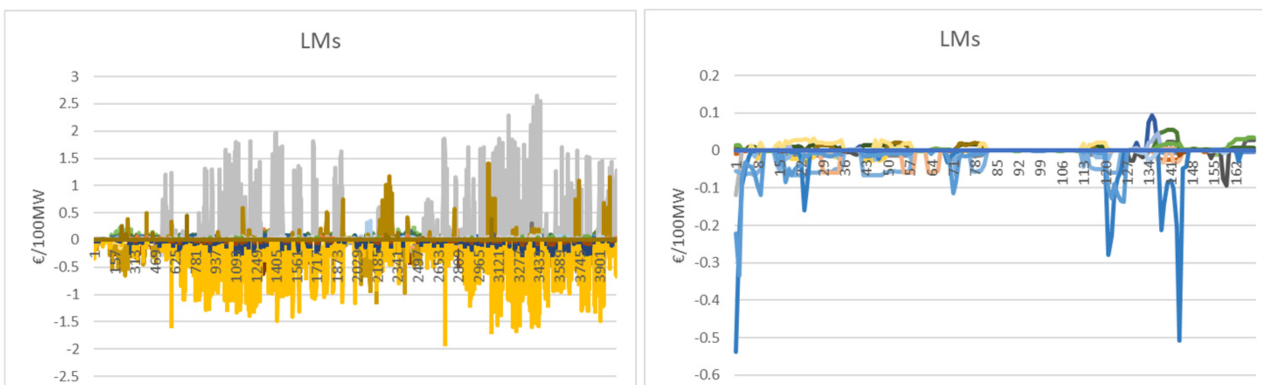
5. Validation (II)

LAGRANGE MULTIPLIER (LM) VALUES

- For the studied case (2030), around 8% of the assets (branches and transformers) show a congestion, i.e., LMs different to zero in, at least, one hour during the study period (24 weeks in this case).



Congestion location in RC Iberia



LM value evolution with time (left: 24 weeks; right: 1 week) for several lines and transformers

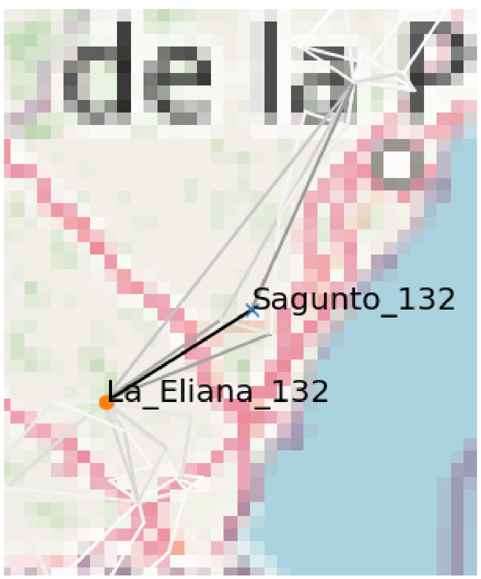
5. Validation (III)

CONGESTION RANKING

- Congestions are ranked and results provided by the pre-processor are checked with external calculations: severity (LM average) and occurrence (no. of congested hours)

	Branch	LM (max(abs))	LM (average (abs))	No. Of congested h	severity x ocurrence
1	Bra_Bescano_132_Salt_132_1	13.8611	5.6620	4835	27374
2	Norte_PS1_2_166	1.3600	1.3218	8736	11547
3	Norte_PS2_36_37	1.3600	1.3218	8736	11547
4	Quinta_Caldeira_PS1_trafo	1.3600	1.3218	8736	11547
5	Quinta_Caldeira_PS2_trafo	1.3600	1.3218	8736	11547
6	Beiriz_PS2_2_228	1.3600	1.3212	8731	11535
7	Sanguedo_PS2_8_9	1.3600	1.3169	8703	11461
8	Leiao_PS2_2_219	1.3600	1.2713	8402	10681
9	Mem_Martins_PS3_2_117	1.3600	1.2387	8185	10139
10	Beiriz_PS2_2_3	1.3600	1.2204	8063	9840
11	Monte_Burgos_PS2_2_133	1.3600	0.9942	6623	6584
12	Lordelo_PS1_2_31	1.3600	0.9925	6612	6562
13	Monte_Burgos_PS2_2_15	1.3600	0.9629	6623	6377
14	Sanguedo_PS2_137_138	1.3600	0.9600	6576	6313
15	Sanguedo_PS1_2_207	1.3600	0.9533	6300	6006
16	Alvelos_PS1_2_87	1.3600	0.9464	6307	5969

Congestion ranking in RC Iberia (first 16)



PTDF values of Sagunto – La Eliana branch
Grey scale (maximum – black; minimum – white)

PTDF VALUES

- This value is used by the pre-processor to estimate the influence of increasing the capacity of a line in the surrounding ones. The higher the PTDF value, the higher the influence.

5. Validation (IV)

FlexPlan

INFLUENCE OF A BRANCH IN A MESHED NETWORK

- A parameter, *alfa*, is calculated that represents the risk of saturation of a branch or transformer when the capacity of a congested line is increased (e.g. by building a parallel line)
- Low *alfas* mean high influence and only alfas lower than 5 are considered with high congestion risk.
- Values provided by the pre-processor are checked with external calculations.

Alfa values for the congested Bescano – Salt line
Grey scale (black: alfa =0; white: alfa >100)

Congested/Influenced	Branch/trafo id	PTDFcong	S rated	PTDF_ratio	P Branch	alfa	abs(alfa)
Congested line	Bescano_132_Salt_132	0.7157	1.3	1.0	1.3	0.0	0.0
Influences line 386	Bra_Bescano_132_Salt_132_1	0.7157	1.3	1.0	1.3	0.0	0.0
Influences line 436	Tra_Bescano_220_Bescano_132_0_1	-0.1399	1.7	-5.1	0.7	-3.7	3.7
Influences line 458	Tra_Juia_220_Juia_132_0_1	0.0661	1.7	10.8	1.0	5.7	5.7

Alfa values for the congested Bescano – Salt line

5. Validation (V)

FlexPlan

PROPOSED CANDIDATES

- The previous case leads to the following candidate proposal:
  - 62 branches and transformers, mainly at distribution.
  - 5 branches and transformers influenced by congested assets.
  - 30 flexible loads
  - 3 storages: 2 hydrogen plants and 1 Liquid Air Energy Storage.

LINE & TRANSFORMER CANDIDATES

- In transmission an element is added in parallel to the existing one; in distribution the asset is substituted by an equivalent of double power.
- The results made us update the cost of branches that were initially considered: a fixed cost was added, a different price for single and double circuits was considered.

LINE & TRANFORMER BY INFLUENCE

- The methodology to calculate the congestion risk in surrounding lines did not work for radial lines (distribution). This was eliminated because lines are synthetic.
- Some lines were considered by “chance” and this was corrected: lines congested at the same time appeared as influence (*alfa* = 0).

5. Validation (VI)

FlexPlan

STORAGE CANDIDATES

- Storage candidates, except for Hydrogen and CAES are not prosed if congestion appeared more than half of the hours considered in the scenario, this happens in about 30 of the selected congestions.
- Storage types have a minimum and maximum size, which restricts their installation.
- The capacity of a battery is calculated in relation to the duration of congestions. If it turns out to be higher than 6 hours, batteries are not an option. This is the main reason for the non existence of this type of candidate.
- Results led to the modification of some constraints, e.g., flow batteries were not selected for congestions longer than 24 hours.

FLEXIBLE LOAD CANDIDATES

- In congested branches' nodes, the existence of loads is checked. If loads exist and they are not flexible they are converted and made flexible.
- Demand Response (DR) is not an option when congestions appear for more than half of the hours.
- In this version, flexible loads had no other restrictions, but afterwards, flexible loads are not an option if congestions last more than 24 hours.
- The effect of considering and not considering flexible load candidates was checked ant the result was that they provide a load curtailment reduction that improves the total cost of the system.

6. Conclusion (I)

FlexPlan

- A methodology has been developed and a software has been created according to it to propose candidates to help a network expansion planning process.
- The methodology is based on a heuristic method that requires parameter tuning to face all the uncertainties related to long-term planning (sensibility analysis is also advisable)
- The software has been integrated with the planning tool and it is being validated in network planning studies at EU regional level.
- The methodology seems to provide adecuate results.
- As result of the validation, some parameters were tuned.
- The software required to be adapted following the evolution of the planning tool design.

6. Conclusion (II)

FlexPlan

- For the analysed Iberian Regional Case, the limitation in the total number of network expansion candidates, to keep the problem tractable, resulted in focusing on the most severe congestions. This limits the use of some of the technologies (as batteries) as solution in this specific cases.
- The development of a network expansion candidate pre-processor helps reduce the size of the planning problem when considering distributed energy resources (DER).
- The expected increase in renewable energy electricity production and the flexibility requirements that this will impose to the power system, makes it appropriate to consider distributed flexible resources in network planning procedure.

7. Reference documents

FlexPlan

FlexPlan public deliverables at https://flexplan-project.eu/publications/:

- **D2.1.** Definition and characterization of services to be provided by flexibility elements
- **D2.2.** Flexibility elements characterization and identification
- **D2.3.** Flexibility elements analysis pre-processor simulation tool (PU methodology)
- **D2.4.** Cost performance analysis and data for storage and flexibility elements

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Thank you…

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