FlexPlan

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

Cost performance analysis and data for storage and flexibility elements

D2.4

Distribution Level	PU
Responsible Partner	EKC
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About FlexPlan

The FlexPlan project 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. This is in line with the goals and principles of the new EC package *Clean Energy for all Europeans,* which emphasizes the potential usage of flexibility sources in the phases of grid planning and operation as alternative to grid expansion. In sight of this, FlexPlan creates a new innovative grid planning tool whose ambition is to go beyond the state of the art of planning methodologies, by including the following innovative features: integrated T&D planning, full inclusion of environmental analysis, probabilistic contingency methodologies replacing the N-1 criterion as well as optimal planning decision over several decades. However, FlexPlan is not limited to building a new tool, but it also uses it to analyse six regional cases covering nearly the whole European continent, aimed at demonstrating the application of the tool on real scenarios as well as at casting a view on grid planning in Europe till 2050. In this way, the FlexPlan project tries to answer the question of which role flexibility could play and how its usage can contribute to reduce planning investments yet maintaining (at least) the current system security levels. The project ends up formulating guidelines for regulators and for the planning offices of TSOs and DSOs. The consortium includes three European TSOs, one of the most important European DSO group, several R&D companies and universities from 8 European Countries (among which the Italian RSE acting as project coordinator) and N-SIDE, the developer of the European market coupling platform EUPHEMIA.

Partners

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List of Abbreviations and Acronyms

Abbreviation/Acronym	**Meaning**
CAES	Compressed Air Energy Storage
D	Distribution (network)
DE	Distributed Energy
DR	Demand Response
GEP	Grid Expansion Planning
LAES	Liquid Air Energy Storage
LM	Lagrange Multiplier
LMP	Locational Marginal Price
OPF	Optimal Power Flow
PST	Phase Shifting Transformer
PTDF	Power Transfer Distribution Factor
RC	Regional Case
ST	Sub-Transmission
SW	Software
T	Transmission (network)
VOLL	Value Of Lost Load

Executive Summary

The present document summarizes the work carried out in task 2.4 of the FlexPlan project, where the main objectives were the following:

- Validate and fine tune the planning candidate pre-processor software (SW) through the analysis of the regional cases.
- Provide assistance regarding the pre-processor to all regional case leaders.
- Understand the main issues related to grid extension in each regional case.

The deliverable presents some of the results obtained during the Pre-processor tuning phase and integration phase, mainly, concerning the Iberian, and Balkan regional cases and partly the Italian regional case.

The document has three main parts. The first two parts are dealing with the two main activities of the pre-processor: the identification of congested assets and the proposal of candidates. The candidate pre-processor tool follows the methodology developed in the frame of the project, whose final version is summarized in [1]. However, the methodology had different versions to accommodate the evolution of the planning tool and as a response to the testing results in the tuning phase, part of which is described in this deliverable. The third part is dealing with the costs of flexible candidates that are selected by the Pre-processor and approved by the GEP, their profitability, and effectiveness in congestions management and other services.

The first main step of the candidate pre-processor SW was to identify which assets of the network are affected by congestion. Congestion points were evaluated, considering occurrence and severity, and ranked, to focus on those assets with the highest problems.

The Pre-processor uses two files as input:

- The grid model and scenario/s are included in the Optimal Power Flow (OPF) input file, which is used by the planning tool to perform an OPF of the Regional Case (RC).
- The OPF output file, which provides the OPF results, including power flows through network assets and other outcomes of the optimization process, such as Lagrange Multipliers (LM), Locational Marginal Prices (LMP) and Power Transfer Distribution Factors (PTDF).

As output, the Pre-processor provides a file with a list of proposed candidates for network extension. These candidates then were included in the Grid Expansion Planning (GEP) input file, which is the input file that the planning tool uses to carry out the planning exercise [2].

Considering the congestion characteristics (LMs, LMPs and power flows), the topology of the grid (nominal power of assets and PTDFs), and the characterization of the flexible resources [1], the Pre-processor proposes a number of candidates.

The pre-processor permits to set a limit to the number of candidates proposed, through a parameter, so that the computational burden for the planning tool can be, somehow, controlled, in this case, by adjusting the number of integer variables linked to the candidate number.

In case of selected regions (Iberian, Italian and Balkan RC), the pre-processor proposed the following candidates:

Iberian RC

- Congested lines and transformers (62 candidates): conventional assets proposed to increase the capacity of congested elements, 2 ST lines (132 kV), 3 transformers, and 57 distribution lines.
- Influenced lines and transformers (5 candidates): distribution lines had no influences; 1 ST line influenced 1 transformer (see Table 2-2); 1 ST line influenced 3 lines and 1 transformer (see Table 2-3, considering the sign of the alfa values).
- Flexible loads (30 candidates).
- Storage (3 candidates): 2 hydrogen plants connected to ST lines and 1 Liquid Air Energy Storage (LAES) connected to distribution.

Italian RC

- Congested lines and transformers (69 candidates): conventional assets proposed to increase the capacity of congested elements, 2 transmission lines, and 67 distribution lines.
- Influenced lines and transformers (8 candidates): distribution lines had no influences; the 2 transmission lines influenced 4 additional transmission lines each.
- Flexible loads (21 candidates).
- Storage (2 candidates): 2 hydrogen plants connected to transmission lines.

Balkan RC

- Congested lines and transformers (37 candidates): conventional assets proposed to increase the capacity of congested elements, 12 transmission lines and 25 distribution lines.
- Flexible loads (25 candidates): 2 flexible loads in transmission and 23 flexible loads in distribution networks.
- Storage (38 candidates): 4 hydrogen storages connected to transmission; 1 flow battery connected to the transmission and 20 flow batteries connected to distribution; 9 Li-ion batteries connected to distribution; 4 Liquid Air Energy Storage (LAES) connected to distribution.

A list of candidates that are proposed by the Pre-processor is used as the input for further analysis done by the GEP. In order to calculate the operational costs of flexible sources and their profitability based on that, as well as their effectiveness in congestion management and other services, GEP simulation is performed. Additionally, OPF simulation on expanded regional cases was required to obtain the data on the nodal prices (LMPs) which is needed for calculation of operational costs of storages.

The results obtained from the Pre-processor have been tested and validated providing the following conclusions:

- The pre-processor does not work with specific requirements for every RC. Specific data of RCs could have been included in the SW as input (within the code), but this information was not available. To find good quality input data is key, but it remains a challenge because many diverse technologies, scenarios, networks, etc. need to be considered.
- Since congestion is severe for high-ranked branches, batteries are not proposed as candidate in most of the cases. This does not mean that batteries are not a good option for the network, but that they are not probably the best choice to cope with this type of congestions, where increasing the capacity of branches and transformers, plus using flexible loads, seems to be a better option.

Battery storage might be a better option for short congestions and to provide other type of services to the network (e.g. ancillary).

- Flexible loads reduce the curtailed generation and load, which reduces the cost of the system.
- The pre-processor was adapted to accommodate to the new formats of planning tool and data, which were adopted to meet the challenges of the FlexPlan project: passing from M€ to €, modifying the cost of the lines, including environmental costs, modifying load flexibility compensation values, including distribution network identification number for T&D decomposition, adapting the formats to cope with the change in the planning procedures (e.g. number of years, hourly time step), etc. To increase efficiency, it is worth trying to plan developments in advance and to consider that, in R&D projects, modifications will arise, so developments should be prepared with that premise in mind.

1 Introduction

The present document summarizes some of the work developed in task 2.4. of FlexPlan project, where the main objectives were the following:

- Validate and fine tune the planning candidate pre-processor software (SW) through the analysis of the regional cases.
- Provide assistance regarding the Pre-processor to all regional case leaders.
- Understand the main issues related to grid extension in each regional case.

The deliverable presents some of the results obtained during the Pre-processor tuning phase and integration phase, mainly, concerning the Iberian and Balkan regional cases.

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2 Identification of congested assets

The first main step of the candidate pre-processor SW is to identify which assets of the network are affected by congestion. Congestion points are evaluated, considering occurrence and severity, and ranked, to focus on those assets with highest problems.

To perform this assessment, the pre-processor uses two files as input:

- The grid model and scenario/s included in the Optimal Power Flow (OPF) input file, which is used by the planning tool to perform an OPF of the Regional Case (RC). The pre-processor uses from this file some values of network assets, such as the topology and nominal power of assets, for example.
- The OPF output file, which provides the OPF results, including power flows through network assets and other outcomes of the optimization process, such as Lagrange Multipliers (LM), Locational Marginal Prices (LMP) and Power Transfer Distribution Factors (PTDF).

As output, the pre-processor provides a file with a list of proposed candidates for network extension. These candidates can then be included in the Grid Expansion Planning (GEP) input file, which is the input file that the planning tool uses to carry out the planning exercise. As output, the planning tool provides the investment decisions, i.e., the planning tool selects the candidates that minimize the cost for network expansion following the restrictions defined in the optimization problem described in [2].

2.1 Iberian RC

The Iberian RC consists of the networks of Spain and Portugal, including transmission (T), sub-transmission (ST) and distribution networks. In the case of Spain, distribution networks were synthetically created based on real distribution networks and, in the case of Portugal, the real topology of the network was included. However, for medium and low voltage networks no real location was provided for substations. The Figure 2-1 shows the transmission and sub-transmission networks included in the Iberian RC grid model.

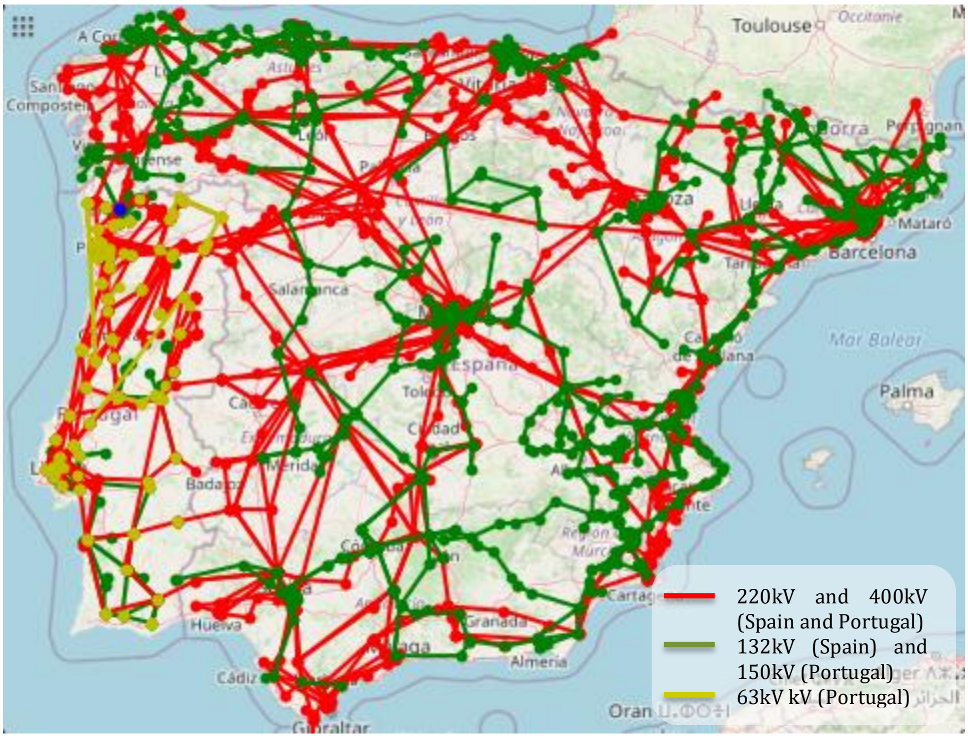

Figure 2-1 – Iberian RC. Transmission and sub-transmission networks

Different cases have been developed to test the pre-processor. The results presented below consider 24 weeks of the Distributed Energy (DE) Scenario year 2030.

2.1.1 LM values

In this case, 826 branches and transformers have LM values different to zero, out of more than 10 700 assets in total. LMs different to zero show the existence of congestions and the mentioned global result means that in around a 7.7% of the assets has a LM different from zero, at least, in one of the more than 4 000 hours considered in the scenario.

The following map shows geographically those lines and transformers with LMs different from zero, i.e., with at least one hour of congestion in the whole scenario period. Distribution lines and transformers are represented by dots and the number is the *id* of the line in the model.

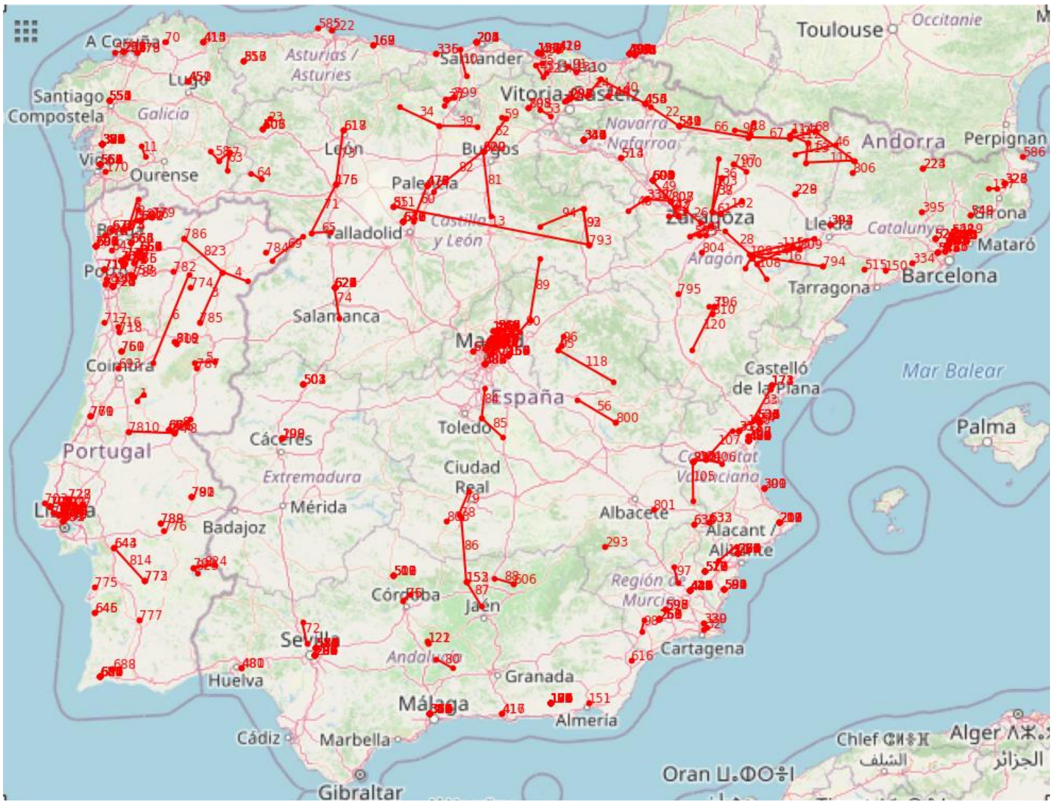

Figure 2-2 – Iberian RC. Lines and transformers with LMS different to zero

The map shows that congestion points are quite distributed in the whole region, but also that are important in the distribution network and in the big cities or around them.

The analysis of the results provides further insights with respect to the characteristics of the congestion points. The pre-processor ranks the network extension candidates based on the severity and occurrence of congestion. Severity represents the LM average value, which is calculated summing up the LM values of each branch or transformer for every hour, in absolute value (independently of the power flow direction) and dividing the result by the total number of hours.

Occurrence of congestion for a branch or transformer is calculated as the sum of the hours that have an LM value different from zero. To sort the congestion points, a value of severity times occurrence is calculated. The following table shows the ranking of congestions for the studied case.

Branch	LM (max(abs))	LM (average (abs))	Congest. Hours	Severity x Ocurrence
Bra_Bescano_132_Salt_132_1	13.8611	5.6620	4835	27374
Norte_PS1_2_166	1.3600	1.3218	8736	11547
Norte_PS2_36_37	1.3600	1.3218	8736	11547
Quinta_Caldeira_PS1_trafo	1.3600	1.3218	8736	11547
Quinta_Caldeira_PS2_trafo	1.3600	1.3218	8736	11547
Beiriz_PS2_2_228	1.3600	1.3212	8731	11535
Sanguedo_PS2_8_9	1.3600	1.3169	8703	11461
Leiao_PS2_2_219	1.3600	1.2713	8402	10681
Mem_Martins_PS3_2_117	1.3600	1.2387	8185	10139
Beiriz_PS2_2_3	1.3600	1.2204	8063	9840
Monte_Burgos_PS2_2_133	1.3600	0.9942	6623	6584
Lordelo_PS1_2_31	1.3600	0.9925	6612	6562
Monte_Burgos_PS2_2_15	1.3600	0.9629	6623	6377
Sanguedo_PS2_137_138	1.3600	0.9600	6576	6313
Sanguedo_PS1_2_207	1.3600	0.9533	6300	6006
Alvelos_PS1_2_87	1.3600	0.9464	6307	5969
Norte_PS4_2_66	1.3600	0.9376	6244	5855
Miraflores_PS1_2_115	1.3600	0.9375	6243	5853
Beiriz_PS2_2_111	1.3600	0.9104	6314	5748
Norte_PS4_2_161	1.3600	0.9153	6244	5715
Miraflores_PS1_2_66	1.3600	0.9021	6243	5632
Lordelo_PS1_138_139	1.3600	0.8626	5870	5064
Mutela_PS2_2_18	1.3600	0.7412	5076	3762
Canicada_PS2_185_187	1.3600	0.7466	4972	3713
Porto_Lagos_PS1_2_3	1.3601	0.6976	4636	3235
Janas_PS2_2_181	1.3600	0.6944	4585	3184
P_Central_132_PS6_2_215	1.3602	0.6709	4500	3019
Barro_PS2_2_3	1.3600	0.6389	4270	2728
Logrono_220_PS3_2_206	1.3602	0.6264	4151	2600
Eiris_220_PS2_4_5	1.3600	0.6219	4114	2558
Gamarra_220_PS2_2_104	1.4086	0.6225	4109	2558
Melancolicos_220_PS4_2_444	1.3600	0.6196	4101	2541
P_Central_132_PS8_3_5	1.3601	0.6105	4097	2501
Canicada_PS2_2_45	1.3600	0.5929	3964	2350
P_Central_132_PS7_2_303	1.3601	0.5897	3957	2334
Eixample_220_PS3_38_41	1.3588	0.5875	3922	2304
Entrenucleos_220_PS1_2_101	1.3600	0.5846	3869	2262

Table 2-1 – Iberian RC. Lines and transformers ranked according to severity and occurrence of their congestion

The LM evolution throughout the time is presented in the following figures.

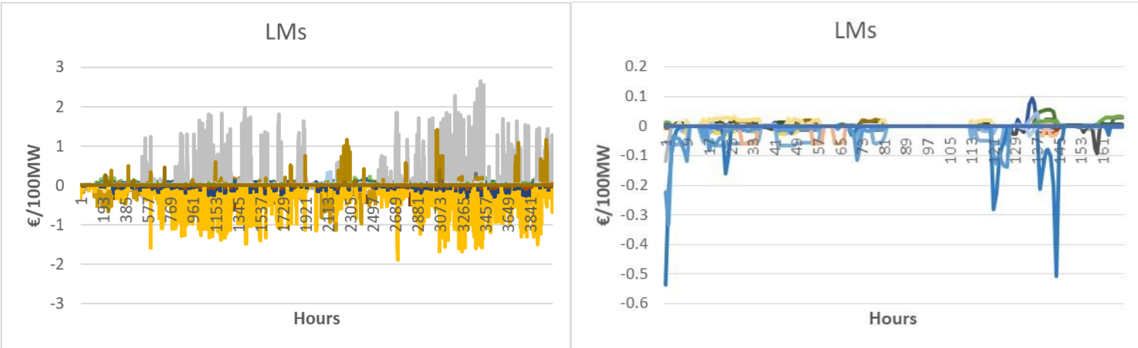

Figure 2-3 – Iberian RC. LM value evolution with time (left: 24 weeks; right: 1 week) for several lines and transformers

In this test, one hundred candidates were provided by the pre-processor. This means that the number of congestion points that were handled was lower, 62, because for some congestion points more than one candidate was proposed. As shown in Table 2-1, congestion affected the following type of assets:

- Sub-transmission (ST) lines (2).
- Transformers (2)
- Distribution lines (57)
- Distribution transformers (1).

2.1.2 PTDF values

The PTDFs represent the paths that the current flows between a power injection and a power extraction node. The PTDF matrix puts in relation all branches and transformers with the nodes of the grid and depends on the topology of the latter. The values given to PTDFs are a per unit of the transferred power flowing through a specific branch/transformer.

The pre-processor tool uses this matrix to estimate the risk of increasing the capacity of a line, as consequence of the network expansion process, in the surrounding lines: increasing the capacity of a line, involves higher power flow in the surrounding lines and this may cause additional congestions. The lines that risk this type of congestion are identified and, when the risk is high, they are also included as candidates for grid expansion.

This effect is shown in the Figure 2-3, where the PTDFs of the lines are mapped (grey scale: black maximum, white minimum), when a power unit is transferred between two substations:

- Between kV Sagunto (132 kV) and El Palmar (400 kV), maximum PTDF: 0.4.
- Between Sagunto (132 kV) and La Eliana (132 kV), maximum PTDF: 0.496.
- Between Logroño (220 kV) and Llodio (20 kV), maximum PTDF: 1 (distribution lines are radial and the PTDF is 1 in them).

Figure 2-4 – Iberian RC. PTDF values. Sagunto – El Palmar(Top) Sagunto – La Eliana (bottom left) Logroño – Llodio (bottom right) (black: maximum; white: minimum)

2.1.3 Influenced congestions (alfa values)

In the pre-processor methodology [1], it was proposed a way to estimate the influence of increasing the capacity of previously congested elements in other surrounding assets. A formula based on PTDF values was proposed and the influence level was estimated through a parameter called *alfa*, which represents the oversaturation in the congested line, when line *l* gets saturated.

$$\alpha_{l,lc} = \frac{P_{lc}^{*} - P_{lc}^{max}}{P_{lc}^{max}} = \frac{\left(PTDF_{K_2,lc} - PTDF_{K_1,lc}\right)}{\left(PTDF_{K_2,l} - PTDF_{K_1,l}\right)} \frac{\left(P_l^{max} - P_l^{0}\right)}{P_{lc}^{max}} \quad (1)$$

Where *K1* and *K2* are both nodes of the congested branch; *lc* is the congested line; *l* the line for which the alfa value is calculated; P^{max}, the nominal power of the asset; and P^{0} the power flow value as result of the OPF. These values are calculated for the hour of maximum congestion (highest LM) of the selected branch.

A low alfa means that the influence is high and vice versa, however the sign of the result is important because if positive it means a direct influence (increase in power flow in *lc* means an increase in power flow in *l*) and if negative the influence is inverse (increase in power flow in *lc* means a reduction in power flow in *l*).

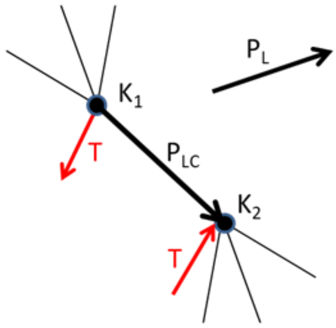

Figure 2-5 – Graphic with parameters for influence calculation (alfa)

A matrix for alfa values is calculated, which has an alfa for each of the branches of the network for the hour of highest LM for a congested branch.

This methodology provides an approximation, because the transmission of power does not need to be between both points of the congested branch or transformer. To get more accurate results, a second OPF would be needed for every congested asset. The latter would permit to know the dispatch differences between both cases (before and after reliving the restriction in a branch) and this would provide the *from* and *end* points for power transfer (real *K1* and *K2*).

Below, an example is provided for the Iberian RC test under study. The alfa values were calculated for the congested line between Bescano (132 kV) and Salt (132 kV) and some of them (ranked from lowest alfa values to highest, in absolute value).

1	Congested/Influenced	Branch/trafo id	PTDFcon	S rated	PTDF_rat	P Branch	alfa	abs(alfa)
2	Congested line	Bescano_132_Salt_132	0.7157	1.3	1.0	1.3	0.0	0.0
3	Influences line 386	Bra_Bescano_132_Salt_132_1	0.7157	1.3	1.0	1.3	0.0	0.0
4	Influences line 436	Tra_Bescano_220_Bescano_132_0_1	-0.1399	1.7	-5.1	0.7	-3.7	3.7
5	Influences line 458	Tra_Juia_220_Juia_132_0_1	0.0661	1.7	10.8	1.0	5.7	5.7
6	Influences line 459	Tra_Juia_220_Juia_132_0_2	0.0661	1.7	10.8	1.0	5.7	5.7
7	Influences line 437	Tra_Bescano_400_Bescano_132_0_1	-0.1445	3.0	-5.0	0.9	-7.9	7.9
8	Influences line 381	Bra_Juia_132_Salt_132_1	0.0472	1.3	15.2	0.5	9.4	9.4
9	Influences line 382	Bra_Juia_132_Salt_132_2	0.0472	1.3	15.2	0.5	9.4	9.4
10	Influences line 383	Bra_Juia_132_Salt_132_3	0.0472	1.3	15.2	0.5	9.4	9.4
11	Influences line 396	Bra_Salt_132_Tordera_132_1	-0.0300	1.3	-23.9	0.6	-13.8	13.8
12	Influences line 397	Bra_Salt_132_Osona_132_1	-0.0254	1.3	-28.2	0.5	-18.1	18.1
13	Influences line 398	Bra_Salt_132_Osona_132_2	-0.0254	1.3	-28.2	0.5	-18.1	18.1
14	Influences line 368	Bra_La_Roca_132_Salt_132_1	0.0214	1.3	33.4	-0.6	19.0	19.0
15	Influences line 369	Bra_La_Roca_132_Salt_132_2	0.0214	1.3	33.4	-0.6	19.0	19.0
16	Influences line 346	Bra_Vic_132_Ripoll_132_1	0.0170	1.3	42.1	0.6	24.1	24.1
17	Influences line 399	Bra_S_Fost_132_Mataro_132_1	0.0128	1.3	55.9	-0.7	26.2	26.2
18	Influences line 380	Bra_Olot_132_Ripoll_132_1	-0.0191	1.3	-37.5	0.3	-29.3	29.3
19	Influences line 349	Bra_Calders_132_Osona_132_1	0.0180	1.3	39.8	-0.3	29.8	29.8
20	Influences line 350	Bra_Calders_132_Osona_132_2	0.0180	1.3	39.8	-0.3	29.8	29.8
21	Influences line 366	Bra_La_Roca_132_Gramanet_132_1	-0.0137	1.3	-52.2	0.6	-29.8	29.8
22	Influences line 367	Bra_La_Roca_132_Gramanet_132_2	-0.0137	1.3	-52.2	0.6	-29.8	29.8
23	Influences line 379	Bra_Olot_132_Salt_132_1	0.0191	1.3	37.5	-0.2	31.5	31.5
24	Influences line 194	Bra_Juia_220_La_Farga_220_3	-0.0563	4.5	-12.7	-0.8	-34.7	34.7
25	Influences line 423	Bra_Tordera_132_Calella_132_1	-0.0111	1.3	-64.5	0.6	-36.6	36.6
26	Influences line 424	Bra_Tordera_132_Sant_Celoni_132_1	-0.0142	1.3	-50.4	0.2	-41.2	41.2
27	Influences line 425	Bra_Tordera_132_Sant_Celoni_132_2	-0.0142	1.3	-50.4	0.2	-41.2	41.2
28	Influences line 465	Tra_La_Roca_220_La_Roca_132_0_1	0.0154	1.7	46.5	0.4	45.8	45.8
29	Influences line 56	Bra_Bescano_220_La_Farga_220_1	0.0531	4.8	13.5	-0.1	47.1	47.1
30	Influences line 57	Bra_Bescano_220_La_Farga_220_2	0.0531	4.8	13.5	-0.1	47.1	47.1

Table 2-2 – Iberian RC. Alfa values for the Bescano-Salt congested line

In the pre-processor, a limit is established, and influence is considered only for alfa values lower than 5, so in this case, only one transformer ("Tra_" code in the name) would be selected (leaving outside the congested one, which appears two times). The next figure shows the alfa values graphically in a grey scale (black: alfa =0; white: alfa >100).

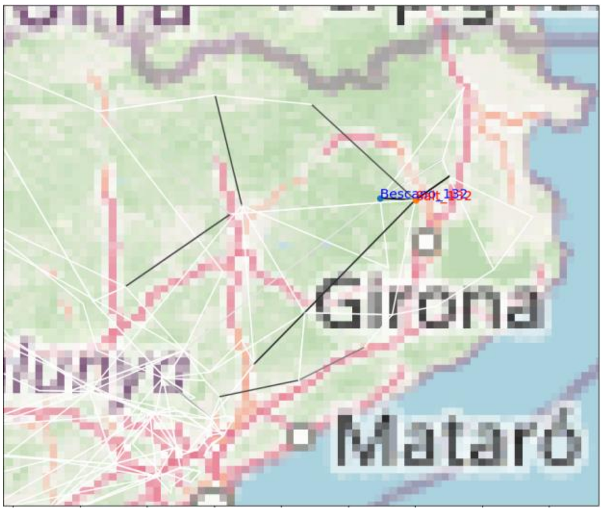

Figure 2-6 – Iberian RC. Alfa values for the Bescano -Salt line

For the other congested line in this case, Sagunto (132 kV)-La Eliana (132 kV), the same check was done.

1	Influence id	Branch	PTDFcongestOr	P rated	PTDF_ratio	Branch	alfa	abs(alfa)
2	Congested line	Sagunto_132_La_Eliana_132	0.4960	1.3	1.0	1.3	0.0	0.0
3	Influences line 259	Bra_Nueva_Mequinenza_400_Aragon_400_1	-0.0016	16.3	-310.0	16.3	0.0	0.0
4	Influences line 1007	Bra_Sabinanigo_220_Sanguesa_220_1	0.0042	3.7	118.1	3.7	0.0	0.0
5	Influences line 1346	Bra_Sagunto_132_La_Eliana_132_1	0.4960	1.3	1.0	1.3	0.0	0.0
6	Influences line 1347	Bra_Sagunto_132_La_Plana_132_1	0.1988	1.3	2.5	-1.3	0.1	0.1
7	Influences line 1634	Tra_Sagunto_220_Sagunto_132_0_1	-0.3052	1.7	-1.6	0.5	-1.5	1.5
8	Influences line 603	Bra_La_Eliana_220_Morvedre_220_1	-0.1784	4.6	-2.8	-3.3	-2.6	2.6
9	Influences line 1362	Bra_Paterna_132_La_Eliana_132_1	0.0617	1.3	8.0	-0.7	4.1	4.1
10	Influences line 895	Bra_Morvedre_220_Sagunto_220_1	-0.2621	5.3	-1.9	-2.3	-4.3	4.3
11	Influences line 1447	Bra_La_Plana_132_El_Ingenio_132_1	0.0722	1.3	6.9	-0.4	4.8	4.8
12	Influences line 1357	Bra_Vinalesa_132_P_Central_132_1	-0.0588	1.3	-8.4	0.6	-4.8	4.8
13	Influences line 1348	Bra_Torrent_132_Paterna_132_1	0.0754	1.3	6.6	-0.2	5.4	5.4
14	Influences line 1434	Bra_La_Eliana_132_Beniferri_132_1	-0.0635	1.3	-7.8	0.4	-5.5	5.5
15	Influences line 1435	Bra_La_Eliana_132_Beniferri_132_2	-0.0635	1.3	-7.8	0.4	-5.5	5.5
16	Influences line 1561	Tra_La_Eliana_220_La_Eliana_132_0_1	0.0840	1.7	5.9	0.4	5.6	5.6
17	Influences line 1562	Tra_La_Eliana_400_La_Eliana_132_0_2	0.0931	3.0	5.3	1.5	6.0	6.0
18	Influences line 670	Bra_Gaussa_400_La_Plana_400_1	-0.0858	12.7	-5.8	-11.3	-6.0	6.0
19	Influences line 1327	Bra_Collado_132_Villamarchante_132_1	0.0405	1.3	12.2	-0.6	7.2	7.2
20	Influences line 1449	Bra_El_Ingenio_132_Castellon_132_1	0.0357	1.3	13.9	-0.6	7.2	7.2
21	Influences line 1450	Bra_El_Ingenio_132_Castellon_132_2	0.0357	1.3	13.9	-0.6	7.2	7.2
22	Influences line 1350	Bra_Torrent_132_Beniferri_132_1	0.0532	1.3	9.3	-0.2	7.8	7.8
23	Influences line 1355	Bra_Vinalesa_132_La_Eliana_132_1	0.0420	1.3	11.8	-0.4	8.1	8.1
24	Influences line 1356	Bra_Vinalesa_132_La_Eliana_132_2	0.0420	1.3	11.8	-0.4	8.1	8.1
25	Influences line 1349	Bra_Torrent_132_Fuente_San_Luis_132_1	-0.0265	1.3	-18.7	0.8	-8.2	8.2
26	Influences line 395	Bra_Beniferri_220_La_Eliana_B_220_1	-0.0822	5.0	-6.0	-3.1	-8.7	8.7
27	Influences line 1536	Tra_Beniferri_220_Beniferri_132_0_1	0.0495	1.7	10.0	0.3	10.6	10.6
28	Influences line 1537	Tra_Beniferri_220_Beniferri_132_0_2	0.0495	1.7	10.0	0.3	10.6	10.6
29	Influences line 1588	Tra_La_Plana_400_La_Plana_132_0_1	-0.0598	3.0	-8.3	1.1	-12.1	12.1
30	Influences line 1360	Bra_Torrefiel_132_Beniferri_132_1	-0.0251	1.3	-19.8	-0.5	-12.2	12.2

Table 2-3 – Iberian RC. Alfa values for the Bescano-Salt congested line

In this case, it can be observed that there are two other lines with alfas equal to zero, but they are not the congested line. In addition, a high PTDF ratio can be observed (1). This means that, in this case, the zero alfa value is related to the fact that the power flow in the line is equal to its nominal power, which means that the line is congested, "by chance" not by influence, at the same hour that the line under study is congested.

This is observed clearly in the next Figure 2-7, where some lines with low alfas (dark) are “far” from the congested line under study.

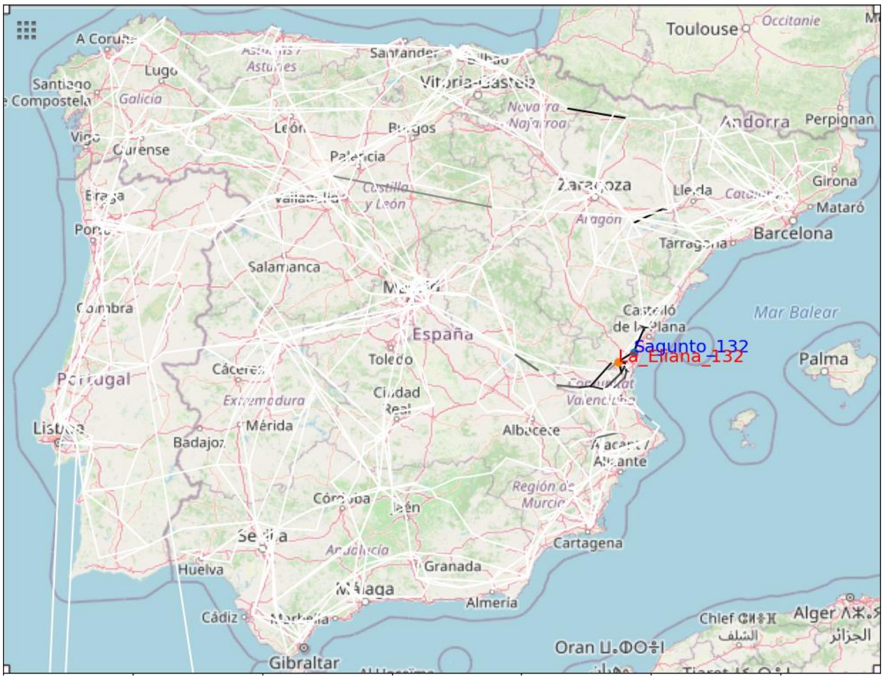

Figure 2-7 – Iberian RC. Alfa values for the Sagunto – La Eliana line

This was identified during the validation phase and the pre-processor SW was adapted to avoid providing this “candidates by chance” as network extension options.

2.2 Italian RC

The Italian RC results were also used for the validation of the pre-processor SW. In this case, the LMs were calculated, providing the results summarized in the next Table 2-4.

In this case, 69 congestions provided up to 100 candidates. The severity of the congestion was high in the identified assets, with 39 branches affected by congestions for more than half of the hours of the year and all the 69 with congestions in more than 3 000 hours a year.

	Branch	LM (max(abs))	LM (average (abs))	No. Of congested h	severity x ocurrence
1	Acline_1440	29222202.2	11034567.733055748	7527.456776000003	83062231652.4
2	PS_1856_PS1_2_72	5036022.4	4473282.80409585	7894.856817999999	35315927244.8
3	PS_164_PS2_70_71	5036000.0	4145676.732181818	7697.771104000001	31912470555.5
4	PS_232_PS1_138_139	5036000.0	3925328.0484283976	6927.371116000001	27192204143.5
5	PS_940_PS1_2_82	5036000.0	3801493.4199452153	6887.856804	26184142317.9
6	PS_246_PS2_2_3	5105139.5	3823261.677416838	6784.971093999999	25940719966.1
7	PS_1710_PS1_133_134	5036000.0	3765681.9441860565	6650.085382000001	25042106450.3
8	PS_615_PS1_2_45	5036000.0	3697589.514298743	6524.371085999999	24124446115.0
9	PS_972_PS1_91_92	5107926.1	3550556.8054207936	6702.6282120000005	23798062212.3
10	PS_1140_PS2_2_50	5018600.0	3617522.2078867373	6400.285356000001	23153174412.1
11	PS_1530_PS2_19_20	5308887.3	3574501.347301364	6306.256794	22541723406.6
12	PS_1971_PS1_109_113	5154361.8	3510434.2368521397	6226.913946000001	21859171906.0
13	PS_1251_PS1_93_98	5038907.6	3501431.419806061	6202.256794000001	21716776812.2
14	PS_946_PS2_49_50	4956528.4	3485747.6846364564	6209.085346000001	21643304868.5
15	PS_615_PS1_2_150	5036000.0	3494026.818642651	6165.771086000002	21543369532.1
16	PS_1536_PS2_2_73	5889209.8	3478386.845800365	6126.028234000002	21308696026.1
17	PS_1170_PS2_2_77	6058509.8	3463573.1855687113	6099.428240000001	21125816099.4
18	PS_240_PS2_2_122	5035814.1	3369257.68024634	5954.342536	20061714320.2
19	PS_1746_PS1_2_109	4979921.4	3360936.7703701295	5941.3710740000015	19968572509.0
20	PS_1825_PS2_2_150	4993219.0	3286659.8318331996	5823.199632000001	19138876323.2
21	PS_867_PS1_3_4	4955952.3	2925035.0273377737	6379.685334000001	18660803065.3
22	PS_293_PS1_96_97	7703572.7	3230280.987476009	5620.628171999999	18156208321.7
23	PS_918_PS1_110_111	5035905.1	3007903.8010559273	5756.056818	17313665182.0
24	PS_1917_PS1_138_139	4992886.1	3009238.4164519655	5308.3425099999995	15974068208.8
25	PS_1247_PS1_84_86	4967427.9	2947628.6711055785	5212.3138739999995	15363965817.8
26	PS_941_PS1_2_134	5031969.5	2824440.797785396	5197.3996720000005	14679747676.0
27	PS_941_PS2_84_85	4991395.8	2730728.75868885	5031.056802000001	13738451495.8
28	PS_305_PS2_36_37	5033983.5	2706598.914331377	4990.513979999999	13507319720.2
29	PS_294_PS1_311_312	4979533.0	2588063.2208295427	4760.713984	12321028766.9
30	PS_1859_PS2_2_179	4993124.4	2632150.9387992513	4644.713928	12225588126.0
31	PS_990_PS2_2_86	4989562.4	2589765.542220449	4586.37114	11877625942.2
32	PS_1721_PS1_83_84	5221012.7	2576578.983066921	4543.342513999999	11706280834.4
33	PS_1375_PS2_69_70	4981005.6	2552183.2285513887	4514.0282879999995	11520627289.8
34	PS_369_PS1_105_106	5367654.7	2545107.9408778	4515.713884	11492979264.9
35	PS_1083_PS1_2_3	5024325.5	2538672.6701299273	4453.0853419999985	11304926055.5
36	PS_995_PS2_2_3	6268011.3	2520641.4364649644	4460.713887999999	11243860262.3
37	PS_727_PS1_2_93	4989466.2	2320039.9466928644	4779.171130000001	11087867933.7
38	PS_1986_PS1_35_39	4980321.7	2429277.2592125083	4421.828181999999	10741846646.7
39	PS_295_PS2_222_223	4992529.3	2374544.7960261633	4383.456845999998	10408714642.3
40	PS_612_PS2_3_4	5096758.6	2404762.7178263664	4241.599678	10200040769.6
41	PS_1921_PS1_111_113	4998431.9	2377087.186146391	4200.8282739999995	9985735061.3
42	PS_989_PS2_49_51	5858347.3	2359279.087412275	4178.456786000001	9858145712.9
43	PS_1192_PS1_96_98	5032014.2	2353122.207503545	4142.256914	9747236733.5
44	PS_1169_PS2_2_128	6293083.6	2353084.6152907885	4134.313912	9728390461.1
45	PS_1256_PS1_61_63	5001269.1	2339658.3207671796	4135.685406	9676090772.2
46	PS_1622_PS2_169_171	5036570.1	2281190.7576511796	4009.68548	9146857458.1
47	PS_622_PS1_2_29	5030875.2	2236916.3012605067	3983.1425780000004	8909956563.0
48	PS_1974_PS1_182_183	5005241.7	2211791.7221075273	3996.628292	8839709372.6
49	PS_1858_PS1_28_29	4996562.3	2197924.553213934	3876.6568819999998	8520599345.3
50	PS_980_PS1_247_249	4989462.7	2175748.6474357387	3848.571168	8373523513.3
51	PS_1341_PS2_2_114	5005400.6	2157467.04283749	3807.656878	8214894224.7
52	PS_1710_PS1_103_104	4981972.7	2130611.429720951	3768.99976	8030273967.3
53	PS_612_PS1_2_30	5096758.6	2120109.308059459	3739.6282299999993	7928420619.1
54	PS_612_PS1_2_132	5096758.6	2117540.8878704826	3734.056904	7907018171.9
55	PS_227_PS1_58_59	4980907.0	2112705.397115397	3737.5140480000005	7896266101.0
56	PS_1729_PS1_62_63	7943864.6	2121057.723741712	3721.799662	7894151919.3
57	Acline_2089	4093307.7	963363.0179513677	8099.171118	7802441931.1
58	PS_1207_PS1_32_33	5029702.4	1989012.2098905328	3501.6569179999997	6964838364.7
59	PS_1171_PS1_160_161	4956784.0	1975086.8129463668	3504.2281940000003	6921154895.5
60	PS_1631_PS2_97_98	5331578.2	1882651.125385131	3515.6568879999995	6618755396.7
61	PS_64_PS1_92_94	5026082.4	1933451.6222338611	3403.8283319999996	6581137410.3
62	PS_602_PS1_2_65	5005133.6	1898336.0044399104	3349.2854540000003	6358069166.5
63	PS_1247_PS1_2_13	4965745.5	1890296.0191310786	3346.742511999999	6326334047.5
64	PS_1201_PS2_32_33	5027878.7	1865179.4797035642	3282.114022	6121731723.9
65	PS_994_PS2_38_39	6268011.3	1839192.7383641296	3253.7140039999995	5984207168.9
66	PS_1246_PS1_2_171	4977154.3	1809985.4029487537	3203.885575999999	5798986125.3
67	PS_923_PS2_3_4	5067397.2	1812401.6833123183	3152.6282679999995	5713828779.8
68	PS_614_PS1_32_33	5044216.2	1760758.2928537983	3107.9139800000003	5472285313.8
69	PS_292_PS1_2_121	4906691.3	1643042.2376335317	3107.542552	5105823668.2

Table 2-4 – Italian RC. Lines and transformers ranked according to severity and occurrence of their congestion

2.3 Balkan RC

The Balkan regional case consists of the networks of Serbia, Montenegro, Croatia, Bosnia and Herzegovina, Slovenia, Macedonia, and Albania including transmission and distribution networks. The distribution networks were synthetically created based on the data obtained from the DiNeMo (Distribution Network Models) platform. The following figure shows the transmission networks of the Balkan regional case in 2025.

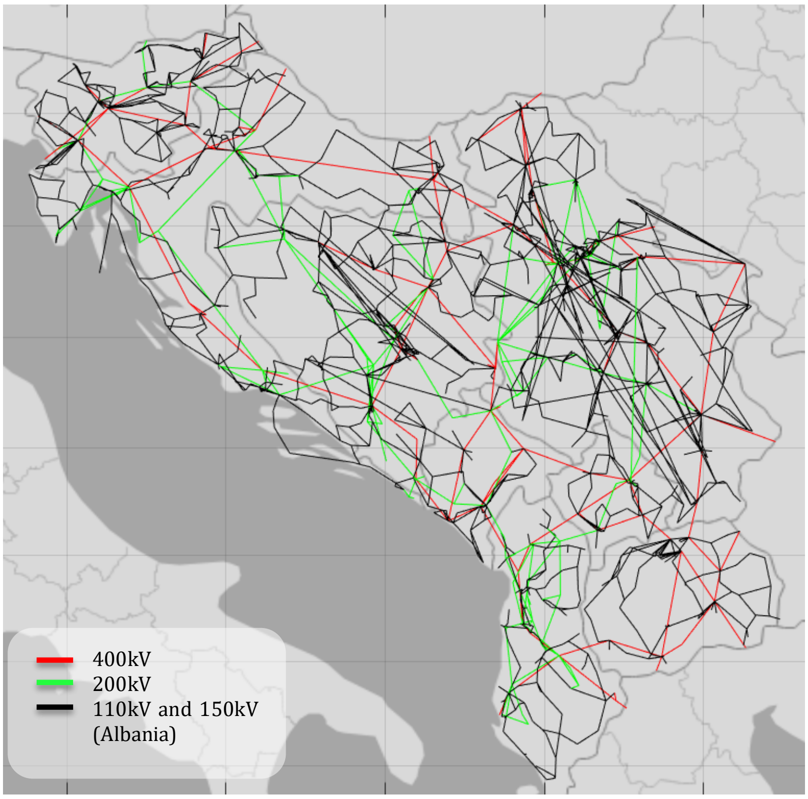

Figure 2-8 – Balkan RC. Transmission network

The results of Balkan RC are used for validation of pre-processor SW, and they consider 4 weeks of DE scenario for 2030. The LMs were calculated and are represented in the Table 2-5. In this case, 63 branches out of 4 089 had LM values different than zero for at least one hour.

	Branch	LM (max(abs))	LM (average (abs))	No of congested hours	severity x ocurrence
1	JPRJPRIS3D2_PS1_307_308	16870663.22	7697944.462	4044	31130487404
2	HKR_HKRASI5_PS2_2_54	16845006.26	3835647.488	2018	7740336631
3	JPEJPEJA210_PS1_2_19	16690252.15	3666248.822	1928	7068527729
4	HPE_HPEHLI5_PS1_392_394	16663086.61	2640982.548	1390	3670965742
5	HPE_HPEHLI5_PS1_521_522	16663086.61	2496567.336	1314	3280489480
6	HPE_HPEHLI5_PS2_2_415	16663086.61	2424342.011	1276	3093460406
7	ATI_ATIRA15_PS2_2_21	16672242.12	2216429.745	1166	2584357082
8	HPE_HPEHLI5_PS1_2_662	16627960.14	1816057.486	956	1736150956
9	HPE_HPEHLI5_PS2_118_121	16627960.14	1816057.486	956	1736150956
10	JPEJPEJA210_PS1_2_292	16648754.77	1399250.834	736	1029848614
11	**ACJBG/JBGD1752-JBG/JBGD2351_1**	2045259.556	210903.0219	4730	997571293.4
12	TETTETOVO 2_PS2_2_27	16679114.64	1156191.901	608	702964675.6
13	HVI_HVINKO5_PS1_trafo	16615938.15	1086665.525	572	621572680.2
14	HVI_HVINKO5_PS3_trafo	16615938.15	1086665.525	572	621572680.2
15	HVI_HVINKO5_PS2_trafo	16615938.15	1044875.578	550	574681567.9
16	HVI_HVINKO5_PS4_trafo	16615938.15	1044875.578	550	574681567.9
17	HMR_HMRACL5_PS1_trafo	16612049.13	1044736.786	550	574605232.5
18	HMR_HMRACL5_PS2_trafo	16612049.13	1044736.786	550	574605232.5
19	HMR_HMRACL5_PS3_trafo	16612049.13	1044736.786	550	574605232.5
20	HMR_HMRACL5_PS4_trafo	16612049.13	1044736.786	550	574605232.5
21	JKRAJKRAG8D_PS1_207_208	16620323.74	927270.0825	488	452507800.2
22	HTE_HTEJER5_PS1_trafo	16601654.46	919263.4051	484	444923488.1
23	HBE_HBENKO5_PS1_trafo	16813360.14	764995.6349	402	307528245.2
24	HPA_HPAG 5_PS1_trafo	16595767.13	721519.4458	380	274177389.4
25	**ACHHE_/HHEKRA5-HZA_/HZAKUC5_1**	462393.8502	104167.303	2592	270001649.5
26	JBGJBGD16D1_PS2_2_57	16642334.72	608428.5808	320	194697145.9
27	**ACWKUP/WKUPRE5-WWDB/WWDBRD5_1**	494435.1963	71968.22532	1802	129686742
28	PRIPRILEP 2_PS1_2_143	16679133.99	414819.0801	218	90430559.45
29	**ACHE BLANCA999-TEB999999999_1**	326619.3561	41131.95087	1494	61451134.6
30	ZEL_RAVNE111_PS1_trafo	16595538.4	227876.2329	120	27345147.95
31	ZEL_RAVNE111_PS4_trafo	16595538.4	227876.2329	120	27345147.95
32	**ACWBUG/WBUGOJ5-WDVA/WDVAKU5_1**	963030.306	33928.72428	682	23139389.96
33	**ACJLEP/JLEPOS5-JVAL/JVALAC5_1**	300800.084	13929.1559	1508	21005167.1
34	ZEL_RAVNE111_PS2_trafo	16593776.9	186083.4393	98	18236177.05
35	ZEL_RAVNE111_PS3_trafo	16593776.9	186083.4393	98	18236177.05
36	VIC_PS1_trafo	16593779.17	186083.4172	98	18236174.89
37	VIC_PS2_trafo	16593779.17	186083.4172	98	18236174.89
38	HKO_HKOMOL5_PS1_trafo	16596254.6	167144.6104	88	14708725.71
39	HKO_HKOMOL5_PS2_trafo	16596254.6	167144.6104	88	14708725.71
40	HKO_HKOMOL5_PS3_trafo	16596254.6	167144.6104	88	14708725.71
41	HKO_HKOMOL5_PS4_trafo	16596254.6	167144.6104	88	14708725.71
42	HKR_HKRASI5_PS1_trafo	16595579.04	167114.3509	88	14706062.88
43	**ACHOB_/HOBROV5-HVE_/HVEBRU5_1**	404327.2824	17891.13507	614	10985156.93
44	ATI_ATIRA15_PS1_135_136	16597353.65	125361.1306	66	8273834.62
45	**ACHHE_/HHEKRA5-HVE_/HVEKAT5_1**	325651.5571	10707.22343	594	6360090.714
46	**ACJBB/JBBAST21-JRH/JRHBBA21_1**	184169.222	6576.590411	822	5405957.318
47	**ACHIM_/HIMOTS5-HZA_/HZAGVO5_1**	606807.3868	10136.40868	352	3568015.856
48	**ACHE BLANCA999-SEVNICA99999_1**	29322.0553	2852.716573	1198	3417554.454
49	**ACHHE_/HHEKRA5-HVE/HVELUKOV_1**	58591.802	2625.438405	892	2341891.057
50	**ACHBI_/HBILIC5-HVE_/HVEGLA5_1**	344688.0287	7938.4317	294	2333898.92
51	**ACHVE_/HVEKAT5-HZA_/HZAGVO5_1**	399104.1808	2506.585097	418	1047752.57
52	**ACWBIL/WBILEC5-WGAC/WGACKO5_1**	265099.8715	4693.214927	210	985575.1346
53	WBLUWBLUK45_PS1_2_158	16597556.78	41797.87651	22	919553.2833
54	HCA_HCAKOV5_PS1_trafo	16595531.76	41792.77686	22	919441.0909
55	HCA_HCAKOV5_PS2_trafo	16595531.76	41792.77686	22	919441.0909
56	**ACHJE_/HJELIN5-HTR_/HTROGI5_1**	270568.6058	3533.384061	134	473473.4642
57	**ACHCR_/HCRIKV5-HHE_/HHEVIN5_1**	345021.1738	2001.287404	168	336216.2838
58	**ACVALANDOVO999-VEC BOGDANCI_1**	263647.843	769.8484055	66	50809.99476
59	**ACHMELIN2(1)99-HSE_/HSENJ 2_1**	7431.9297	126.8829284	264	33497.09311
60	**ACWGRU/WGRUDE5-WSBR/WSBRIJ5_1**	283735.3041	1003.058784	32	32097.88107
61	**ACHNE_/HNEDEL5-HE FORMIN999_1**	466139.1093	1173.88512	22	25825.47263
62	**ACPOLJE9999999-TETOL9999999_1**	34134.6528	107.0589074	60	6423.534444
63	**ACWMOS/WMOST15-WMOS/WMOST25_1**	3814.2245	9.605418842	22	211.3192145

Table 2-5 – Balkan RC. Branches ranked according to severity and occurrence of their congestion

As explained in chapter 2.1.1, the congestion candidates are ranked by the Pre-processor based on severity and occurrence of congestion where severity represents the average value of LM ("LM average(abs)" column in the table), while occurrence is the sum of the hours that have LM values different from zero ("No of congested hours" column). Transmission network branches (lines and transformers) in the previous table are distinguished from distribution branches by the fact their names begin with "AC" and are bolded. It can be concluded that congestions dominate in distribution networks and that they are also the most severe. This is not surprising considering that due to the congestions (lack of capacity) in distribution networks, demand curtailment occurs, which is very expensive (10,000 €/MWh). For this reason, most of the candidates, proposed by the pre-processor later, will relate to congestions in distribution networks.

According to the previous Table 2-5, congestions affected the following type of assets:

- Transmission branches (24)
- Distribution branches (39)

The Figure 2-9 shows the branches' geographical representation, including their ordinal number from the Table 2-5. The transmission branches are represented in navy blue and the distribution networks as dots in light blue color.

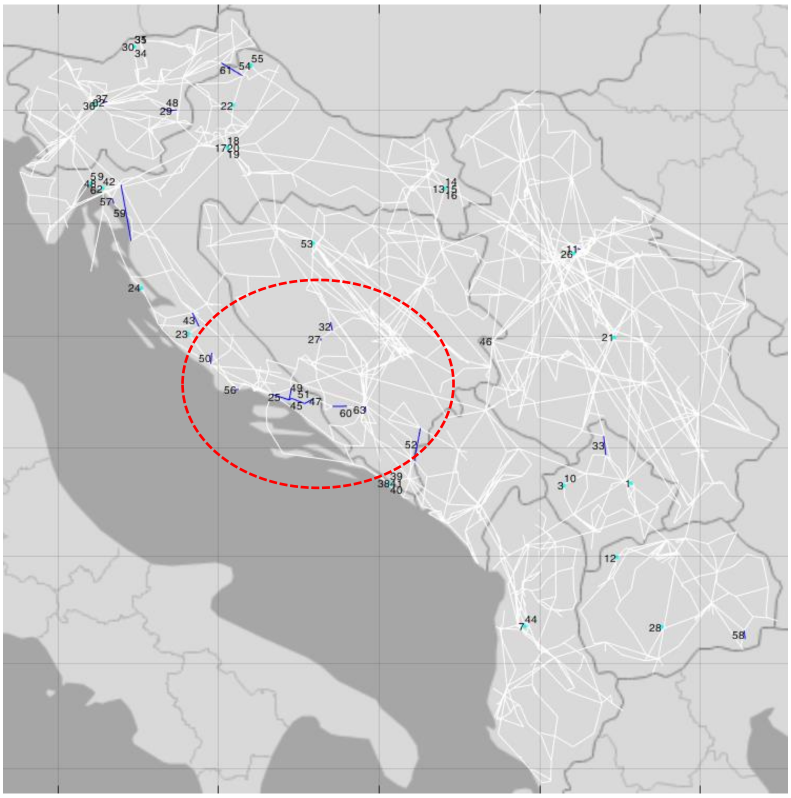

Figure 2-9 – Balkan RC. Branches with LMs different to zero

The previous map shows that congestions related to distribution networks are distributed throughout the region and those related to the transmission network have one area in which they are more concentrated than others. This area includes the border of Bosnia and Herzegovina and Croatia and, according to OPF results for 2030, represents an area of high generation curtailment (about 65% of total generation curtailment for 2030 occurs in this area). The generation curtailment occurs due to the lack of capacity in the 110 kV network, which makes it impossible to extract energy generated from solar and wind power plants connected to transmission network.

The following figure represents the LM evolution throughout the scenario year for some of the most congested branches in transmission and distribution networks.

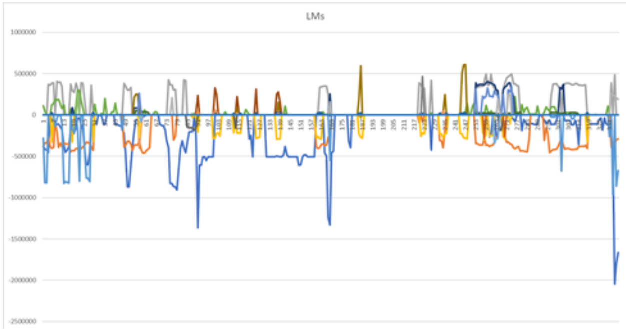

Figure 2-10 – Balkan RC. LM value evolution with time

As discussed in section 2.1.3, the Pre-processor also evaluates the impact of increasing the capacity of congested elements on other assets in their surroundings through the alpha parameter. As explained, the lower the value of the alpha parameter, the greater the impact on that branch. As an example, below is a Table 2-6 with branches that have an alpha parameter less than 5 for the highest congestion in the network. Alpha parameters were calculated for the congested 110 kV line between Beograd 17 and Beograd 23 and sorted from the lowest to the highest absolute value. In addition to the congested branch, there are two other branches with an alpha parameter equal to zero. This is not because these branches are under a strong influence, but because their power flows are equal to the nominal values of their capacities, that is, they are congested at the same hour. This means that the last 2 branches in the Table 2-6 will also be proposed by the Pre-processor as candidates.

For the other congested line in this case, 110 kV line between substations Zakucac and Kraljevac, the same check was done - Table 2-7.

Branches that have a zero alpha parameter are a congested branch and a branch that has nominal power flowing at the same hour, so they are not relevant. The next four branches are the ones that are strongly influenced and which, as will be seen in chapter 3.3, will be proposed by the Pre-processor.

Congested/Influenced	Branch/trafo id	PTDFcongestOr-PTDFcongestEnd	S rated	PTDF_ratio	P Branch	alfa	abs(alfa)
Congested line	JBG/JBGD1752-JBG/JBGD2351	0.9326	1.766	1	1.766	0	0
Influences line 69	ACWKUP/WKUPRE5-WWDB/WWDBRD5_1	-1.00E-04	1.15	-9326	-1.15	0	0
Influences line 80	ACWWB/WWBALJC5-WWDB/WWDBRD5_1	1.00E-04	1.15	9326	1.15	0	0
Influences line 263	ACJBG/JBGD1752-JBG/JBGD2351_1	0.9326	1.766	1	1.766	0	0
Influences line 282	ACJBG/JBGD2351-JBGD/JBGD455_1	-0.0674	1.766	-13.83679525	1.6099	-1.223059875	1.223059875
Influences line 319	ACJBGD/JBGD455-JTTB/JTTBGD5_1	-0.0674	1.766	-13.83679525	1.4849	-2.202447987	2.202447987

Table 2-6 - Balkan RC. Alfa values for the Beograd 17 - Beograd 23 congested line

Congested/Influenced	Branch/trafo id	PTDFcongestOr-PTDFcongestEnd	S rated	PTDF_ratio	P Branch	alfa	abs(alfa)
Congested line	HHE_/HHEKRA5-HZA_/HZAKUC5	0.7773	1.23	1	1.23	0	0
Influences line 390	ACHHE_/HHEKRA5-HVE/HVELUKOV_1	0.117	1.23	6.643589744	-1.23	0	0
Influences line 392	ACHHE_/HHEKRA5-HZA_/HZAKUC5_1	0.7773	1.23	1	1.23	0	0
Influences line 503	ACHVE_/HVEKAT5-HZA_/HZAGVO5_1	0.1058	0.8	7.346880907	0.753	0.280734474	0.280734474
Influences line 396	ACHIM_/HIMOTS5-HZA_/HZAGVO5_1	-0.1058	0.8	-7.346880907	-0.7441	-0.333894831	0.333894831
Influences line 161	ACWGRU/WGRUDE5-HIM_/HIMOTS5_1	-0.1058	0.8	-7.346880907	-0.5691	-1.379182765	1.379182765
Influences line 160	ACWGRU/WGRUDE5-WSBR/WSBRIJ5_1	0.0895	1.035	8.684916201	0.7874	1.748280692	1.748280692

Table 2-7 - Balkan RC. Alfa values for the Zakucac - Kraljevac congested line

3 Proposal of candidates

Considering the congestion characteristics (LMs, LMPs and power flows), the topology of the grid (nominal power of assets and PTDFs) and the characterization of the flexible resources [1], the pre-processor proposes a number of candidates.

The pre-processor permits to set a limit to the number of candidates proposed, through a parameter, so that the computational burden for the planning tool can be, somehow, controlled, in this case, by adjusting the number of integer variables linked to the candidate number.

3.1 Iberian RC

In the test case represented by Table 2-1 congestion results, the pre-processor proposed the following candidates:

- Congested lines and transformers (62 candidates): conventional assets proposed to increase the capacity of congested elements, 2 ST lines (132 kV), 3 transformers and 57 distribution lines.
- Influenced lines and transformers (5 candidates): distribution lines had no influences; 1 ST line influenced 1 transformer (see Table 2-2); 1 ST line influenced 3 lines and 1 transformer (see Table 2-3, considering the sign of the alfa values).
- Flexible loads (30 candidates).
- Storage (3 candidates): 2 hydrogen plants connected to ST lines and 1 Liquid Air Energy Storage (LAES) connected to distribution.

The analysis of the results, confronted to the implemented methodology at the time of the simulation (v.1.8), led to the following conclusions:

- **Storage** candidates:
  - Storage candidates, except for Hydrogen and Compressed Air Energy Storage (CAES), were not proposed if congestion appeared more than half of hours considered in the scenario. This is the case in almost 30 of the selected congestions.
  - If the percentage of congestion hours not relieved by the storage candidate was higher than 20%, batteries were not an option. This was eliminated when the year was represented by representative weeks, instead of by all year hours, since weeks were not consecutive.
  - Storage types have a minimum and maximum size, which restricts their installation.
  - If the capacity of the battery turns out to be higher than 6 hours (related to the duration of congestions), batteries (Li-ion and NaS) are not an option. This is the main reason for the no existence of candidate batteries.

    Flow batteries were initially considered to be able to cope with congestion durations longer than 6 hours. However, this meant their size could be really big (in terms of energy), for severe congestions. Therefore, for flow batteries, a maximum limit of 24 hours was set (for longer congestions they are not an option). The configuration change that was included in the tool is shown graphically in Table 6-1 of the pre-processor methodology document [1]. Below and extract of that table is presented for two versions of the SW, before and after the modifications, with the focus on the modifications that took place in relation with this issue.

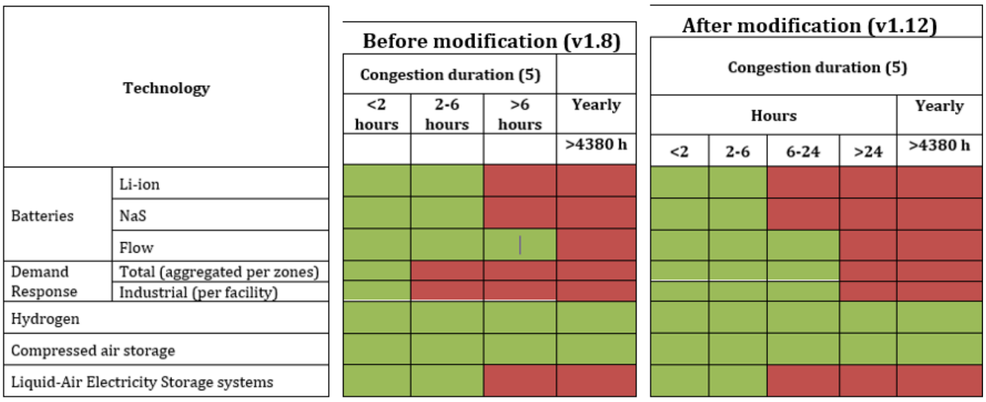

Table 3-1 – Technologies proposed by pre-processor (green) according to congestion duration as described in the methodology (v.1.8., left; v1.12, right)

- **Flexible load** candidates (Demand Response):
    - According to the methodology, it is checked if there are loads at any of the two buses of the congested branch or transformer. If this is the case and they are not flexible, they are made flexible in a percentage, which depends on the type of load.
    - In the current version of the software, only values for generic types of load are implemented: "industrial" and "commercial" in transmission (if no type is specified, "industrial" is used as default) and "mixed" in distribution.
    - Demand response (DR) is not an option when congestions appear more than half of the yearly hours.
    - If the event was longer than two hours, it was considered that flexible loads were not an option, because of the annoyance that this would cause to consumers. In this version of the tool, this part of the methodology had not been implemented and that is why there were so many load candidates.
    - In subsequent versions of the tool the limit value of flexible loads was extended to 24 hours (see Table 3-1).
    - A comparison of the GEP problem results was performed to understand the influence of having Flexible Loads as candidate with long congestions. One hypothesis was that flexible loads would not be selected because lines would provide a higher cost reduction to face severe congestions. However, the results, summarized in the table below, showed the opposite: it was more profitable to instal flexible loads because they permitted to reduce generation curtailment and, mainly, load curtailment (in this case, no investment cost was assigned to flexible loads).

	GEP results: Costs (€)					
	Total	Geneneration	Generation curtailment	Load curtailment	Load reduction	Load shifting
Without flexible loads	167336973	1493496	138641440	26289169	0	0
With flexible loads	167336669	1493421	138641823	26296594	67	140
Difference (without – with)	304	75	-383	-7425	-67	-140

***Table 3-2** – Iberian RC. GEP results (costs)* comparation *for cases with and without Flexible Loads*

	GEP results: Investment decisions (x out of y)			
	Flexible loads	Line	Transformer	Storage
Without flexible loads	-	15/62	3/12	0/26
With flexible loads	5/5	11/57	3/12	0/26
Difference (without – with)	-5/5	4/5	0/0	0/0

Table 3-3 – Iberian RC. GEP results (investment decisions) comparation for cases with and without Flexible Loads

- **Lines and transformers**:
  - According to the methodology, in transmission, an additional element is added in parallel to the existing line or transformer to increase the capacity of the congested one. In distribution, the element is substituted by an equivalent one of double power and half impedance.
  - In some initial tests, we observed that the price proposed by the pre-processor for lines was probably too low. We checked the input data with a system operator and, as result, the following modifications were included in the input data and code:
    - Initially, the cost of lines was calculated just as variable cost (euros per length, dependent of voltage), so for very short lengths the cost was very low. It was decided to add a fixed cost value for every voltage level.
    - Cost differences for single and double circuits were included in the last version. This characteristic is evaluated based on the nominal current of the lines (no other information was available to identify this).
    - The CO_2 footprint costs (€/km during 50 year lifetime) were included as input (environmental costs were not available in previous versions of the tool).
- **Lines and transformers proposed by influence**:
  - A formula is used to calculate the level of influence of certain lines on others (1).
  - An asset, branch or transformer, should have a maximum value of alfa equal to 5 to be proposed as "influenced" candidate.
  - A limit is set to the number of candidates proposed via influence. Per congested branch or transformer, a maximum of 5 influences or a 30% of the maximum number of candidates, when this value is lower than 5, is considered.
  - The proposed methodology made that no influences appeared at distribution, because they are radial. Considering equation (1), this configuration makes that the denominator is zero ($PTDF_{K2,l} - PTDF_{K1,l}$) and, therefore, alfa very high.

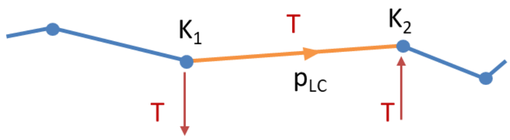

Figure 3-1 – Graphic with parameters for influence calculation (alfa). Distribution lines

- To solve this, it was proposed that a number of influenced lines were considered to both sides of the congested lines (considering only distribution until the transformer). Finally, it was agreed not to consider the effect of the influence in distribution, since they are mostly synthetic and simplified lines and added a high number of conventional assets as candidates.
- it was observed that some distant lines were considered influenced because they had an alfa value equal to zero, but this was not related to the PTDF value but to the fact that they were congested at the same time that asset under analysis (influence by chance). The software was modified to avoid including these lines as influenced lines (alfa equal to zero was excluded from the list).

3.2 Italian RC

The Italian RC tested (see LM results in Table 2-4), provided the following candidates, with the version of the SW at the time when the studies were carried out:

- Congested lines and transformers (69 candidates): conventional assets proposed to increase the capacity of congested elements, 2 transmission lines and 67 distribution lines.
- Influenced lines and transformers (8 candidates): distribution lines had no influences; the 2 transmission lines influenced 4 additional transmission lines each.
- Flexible loads (21 candidates).
- Storage (2 candidates): 2 hydrogen plants connected to transmission lines.

These results showed an agreement with the version of the pre-processor deployed at the time of the tests.

Additionally, storage candidates were compared to candidate lines, both provided by the pre-processor. This was made for one of its latest versions, before the one deployed to perform the final tests of the planning tool. The objective was to analyse if the flexibility options proposed by the pre-processor made sense in terms of costs compared to lines.

Storage id	P (MW)	E (MWh)	CAPEX (€/kW)	CAPEX (€/kWh)	Total Cost (€)
H2_AC_3227_AC_3145_AC_3227	1.5	2552	500		750000
H2_AC_2875_AC_2941_AC_2875	1.5	2219	500		750000
FlowBattery_PS_989_PS2_51_PS_989_PS2_47_PS_989_PS2_51	0.0682	0.4	200	200	177320
FlowBattery_PS_1693_PS1_33_PS_1693_PS1_26_PS_1693_PS1_33	0.0682	0.3	200	200	150040

Table 3-4 – Italian RC. Analysis of four storage candidates' estimated price.

AC Branch id	V (kV)	P (MW)	I (A)	length (km)	Fixed cost (€)	Variable cost (€/km)	Variable cost Environmental (€/km for 50 years)	Total Cost (€)
AC_AC_3139_AC_3227	132	75	328	26.40	300000	250000	17500	7362000
AC_AC_2941_AC_2875	132	75	328	10.80	300000	250000	17500	3189000
PS_989_PS2_49_51	20	6.82	197	0.57	60000	60000	17500	104008
PS_1693_PS1_31_33	20	6.82	197	0.16	60000	60000	17500	72501

Table 3-5 – Italian RC. Analysis of four line candidates' estimated price.

Table 3-4 shows the total cost of storage candidates, in this case, two hydrogen plants and two flow batteries. In the case of the hydrogen plants, the cost is directly related to the power of the plant, while in the case of flow batteries the capacity or nominal energy (E) has also influence in the cost.

In the case of lines, Table 3-5 shows that the cost for transmission lines is higher than that of the storage. However, in the case of distribution lines the cost is lower and, therefore, lines are the preferred option for the GEP, in these locations. The main reason for this is the short length of the lines, which is the parameter that has a direct influence in their cost.

The validations carried out testing the Italian RC raised questions on the values defined in the pre-processor SW for candidates' characteristics and this led to its fine tuning. Below, there are some of the aspects that were modified as result of these tests:

- Flexible load lifetime and investment costs.
- The lifetime of some technologies was corrected based on the methodology (bugs in the code).
- Value of Lost Load (VOLL) of flexible loads.
- The compensations for consumption reduction and shift.
- A low cost of lines led to considering a fixed cost, in addition to that variable with length, which was previously not considered.
- Initially one "impedance per length" value was considered, but then it was decided to use one value for lines in transmission and a different one for cables in distribution.

3.3 Balkan RC

In the test case represented by Table 2-5 congestion results, the pre-processor proposed the following candidates:

- Congested lines and transformers (37 candidates): conventional assets proposed to increase the capacity of congested elements, 12 transmission lines and 25 distribution lines.
- Flexible loads (25 candidates): 2 flexible loads in transmission and 23 flexible loads in distribution networks.
- Storage (38 candidates): 4 hydrogen storages connected to transmission; 1 flow battery connected to transmission and 20 flow batteries connected to distribution; 9 Li-ion batteries connected to distribution; 4 Liquid Air Energy Storage (LAES) connected to distribution.

The analysis of the results, confronted to the implemented methodology at the time of the simulation, led to the following conclusions:

- **Storage** candidates:
  - Hydrogen Storage (H2) appeared as a candidate in cases where congestion lasted from 5 to 32 hours,
  - Flow batteries appeared as candidates in cases where congestion lasted from 2 to 8 hours,
  - Lithium-ion batteries appeared as candidates in cases where congestion lasted from 2 to 3 hours.
  - As for Liquid Air Energy Storage (LAES), all congestions for which this type of storage was proposed as candidate, lasted for 3 hours,
  - All proposed storage candidates and related congestion durations are in accordance with the Table 3-1.
- **Flexible load candidates:**
  - All loads within the region were initially set as non-flexible but those loads that were chosen by the pre-processor were made flexible in a certain percentage.
  - Congestion duration of branches for which flexible loads were selected as candidates were from 2 to 9 hours.
  - All flexible loads that were proposed are related to the most serious congestions from the Table 2-5. In cases where there was no load on any side of the congested branch and when the duration of congestion was longer than half a year (congested branch under serial number 11 in the Table 2-5), flexible load was not proposed as candidate.
- **Lines and transformers**:
  - Lines and transformers (both modelled as branches in the Balkan case) were present as candidates for almost every congestion that was potentially being resolved because they do not have congestion duration limits. They were the most dominant candidates in distribution networks, which is not surprising, considering that they are short, and their price is proportional to their length.

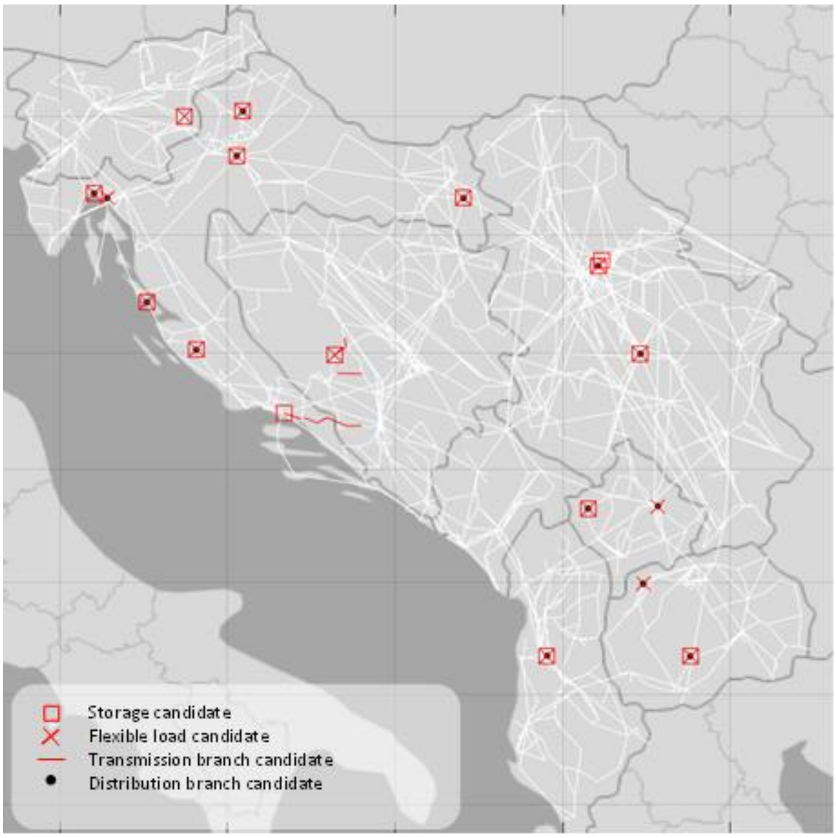

Figure 3-2 – Geographical representation of different types of candidates

For testing purposes, the number of candidates that the Pre-processor could propose was limited to 100. The number of congestions that were handled was lower than that, because some congestions had a larger number of proposed candidates, as can be seen from the previous figure and the following table. The congestions from the Table 2-5 can be seen again in the following table including their maximal duration and the types of candidates that were proposed for handling them.

Table 3-6 – Congestions and types of proposed candidates

No.	Branch	Congestion duration	Storage candidate H2	Storage candidate Flow	Storage candidate Li-ion	Storage candidate LAES	Branch candidate	Flexible load candidate
1	JPRJPRIS3D2_PS1_307_308	9	×	×	×	×	✓	✓
2	HKR_HKRASI5_PS2_2_54	9	×	×	×	×	✓	✓
3	JPEJPEJA210_PS1_2_19	8	×	×	×	×	✓	✓
4	HPE_HPEHLI5_PS1_392_394	8	×	✓	×	×	✓	✓
5	HPE_HPEHLI5_PS1_521_522	8	×	✓	×	×	✓	×
6	HPE_HPEHLI5_PS2_2_415	8	×	×	×	×	✓	×
7	ATI_ATIRA15_PS2_2_21	7	×	✓	×	×	✓	✓
8	HPE_HPEHLI5_PS1_2_662	7	×	✓	×	×	✓	✓
9	HPE_HPEHLI5_PS2_118_121	7	×	✓	×	×	✓	✓
10	JPEJPEJA210_PS1_2_292	4	×	✓	×	×	✓	✓
11	**ACJBG/JBGD1752-JBG/JBGD2351_1**	29	✓	×	×	×	✓	×
12	TETTETOVO 2_PS2_2_27	5	×	×	×	×	✓	✓
13	HVI_HVINKO5_PS1_trafo	3	×	✓	×	×	✓	✓
14	HVI_HVINKO5_PS3_trafo	3	×	✓	×	×	✓	✓
15	HVI_HVINKO5_PS2_trafo	3	×	✓	✓	✓	✓	✓
16	HVI_HVINKO5_PS4_trafo	3	×	✓	✓	✓	✓	✓
17	HMR_HMRACL5_PS1_trafo	3	×	✓	✓	×	✓	✓
18	HMR_HMRACL5_PS2_trafo	3	×	✓	✓	×	✓	✓
19	HMR_HMRACL5_PS3_trafo	3	×	✓	✓	×	✓	✓
20	HMR_HMRACL5_PS4_trafo	3	×	✓	✓	×	✓	✓
21	JKRAJKRAG8D_PS1_207_208	3	×	✓	×	×	✓	✓
22	HTE_HTEJER5_PS1_trafo	3	×	✓	✓	✓	✓	✓
23	HBE_HBENKO5_PS1_trafo	3	×	✓	✓	✓	✓	✓
24	HPA_HPAG 5_PS1_trafo	2	×	✓	✓	×	✓	✓
25	**ACHHE_/HHEKRA5-HZA_/HZAKUC5_1**	32	✓	×	×	×	✓	×
26	JBGJBGD16D1_PS2_2_57	2	×	✓	×	×	✓	✓
27	**ACWKUP/WKUPRE5-WWDB/WWDBRD5_1**	26	✓	×	×	×	✓	×
28	PRIPRILEP 2_PS1_2_143	4	×	✓	×	×	✓	✓
29	**ACHE BLANCA999-TEB999999999_1**	5	✓	✓	×	×	×	×
30	ZEL_RAVNE111_PS1_trafo	1	×	×	×	×	×	×
31	ZEL_RAVNE111_PS4_trafo	1	×	×	×	×	×	×
32	**ACWBUG/WBUGOJ5-WDVA/WDVAKU5_1**	5	×	×	×	×	✓	×
33	**ACJLEP/JLEPOS5-JVAL/JVALAC5_1**	10	×	×	×	×	×	×
34	ZEL_RAVNE111_PS2_trafo	1	×	×	×	×	×	×
35	ZEL_RAVNE111_PS3_trafo	1	×	×	×	×	×	×
36	VIC_PS1_trafo	1	×	×	×	×	×	×
37	VIC_PS2_trafo	1	×	×	×	×	×	×
38	HKO_HKOMOL5_PS1_trafo	2	×	×	×	×	×	×
39	HKO_HKOMOL5_PS2_trafo	2	×	×	×	×	×	×
40	HKO_HKOMOL5_PS3_trafo	2	×	×	×	×	×	×
41	HKO_HKOMOL5_PS4_trafo	2	×	×	×	×	×	×
42	HKR_HKRASI5_PS1_trafo	2	×	×	×	×	×	×
43	**ACHOB_/HOBROV5-HVE_/HVEBRU5_1**	23	×	×	×	×	×	×
44	ATI_ATIRA15_PS1_135_136	1	×	×	×	×	×	×
45	**ACHHE_/HHEKRA5-HVE_/HVEKAT5_1**	3	×	×	×	×	×	×
46	**ACJBB/JBBAST21-JRH/JRHBBA21_1**	7	×	×	×	×	×	×
47	**ACHIM_/HIMOTS5-HZA_/HZAGVO5_1**	3	×	×	×	×	✓	×
48	**ACHE BLANCA999-SEVNICA99999_1**	5	×	×	×	×	×	×
49	**ACHHE_/HHEKRA5-HVE/HVELUKOV_1**	27	×	×	×	×	×	×
50	**ACHBI_/HBILIC5-HVE_/HVEGLA5_1**	13	×	×	×	×	×	×
51	**ACHVE_/HVEKAT5-HZA_/HZAGVO5_1**	4	×	×	×	×	✓	×
52	**ACWBIL/WBILEC5-WGAC/WGACKO5_1**	5	×	×	×	×	×	×
53	WBLUWBLUK45_PS1_2_158	1	×	×	×	×	×	×
54	HCA_HCAKOV5_PS1_trafo	1	×	×	×	×	×	×
55	HCA_HCAKOV5_PS2_trafo	1	×	×	×	×	×	×
56	**ACHJE_/HJELIN5-HTR_/HTROGI5_1**	3	×	×	×	×	×	×
57	**ACHCR_/HCRIKV5-HHE_/HHEVIN5_1**	5	×	×	×	×	×	×
58	**ACVALANDOVO999-VEC BOGDANCI_1**	1	×	×	×	×	×	×
59	**ACHMELIN2(1)99-HSE_/HSENJ 2_1**	4	×	×	×	×	×	×
60	**ACWGRU/WGRUDE5-WSBR/WSBRIJ5_1**	1	×	×	×	×	✓	×
61	**ACHNE_/HNEDEL5-HE FORMIN999_1**	1	×	×	×	×	×	×
62	**ACPOLJE9999999-TETOL9999999_1**	1	×	×	×	×	×	×
63	**ACWMOS/WMOST15-WMOS/WMOST25_1**	1	×	×	×	×	×	×

The table shows that the first 29 congestion points were treated, however, there are also 4 congestions that are ranked lower but were taken into account. However, these four branches were not treated because of their congestion, but because of the high influence of the reinforcement of some of the congested branches that are ranked higher, that is, because of the low value of the alpha parameter (as explained in chapter 2.1.3). The following image (Figure 3-3) shows a zoomed-in view of the network on the border between Croatia and Bosnia and Herzegovina from Figure 3-2. The branches shown are the branches from the example represented in Table 2-7. The marked branch is a highly ranked congested branch Zakucac - Kraljevac, and the remaining four branches are congested as well but are proposed due to the high influence of reinforcement of congested branch that is highly ranked.

Figure 3-3 – Geographical representation of different types of candidates

Other aspects that were identified during the pre-processor tuning:

- Some not connected buses were identified. This caused LMP values of zero an made the pre-processor crash.
- Phase Shifting Transformers (PST) were connected to an interconnection line, and this caused problems because PSTs were not included in the PTDF matrix in the OPF output. We would need to have their settings to model the power flows correctly, because they can control the power flow through a line. In addition, as being at the border of the network, they did not have any influence, so they were eliminated.

4 Costs and performance of flexible resources

This chapter provides an overview of the costs of accepted flexible resources (CAPEX and OPEX), their effectiveness in removing congestion, their availability for services other than congestion relief as well as their acceptance by the GEP tool. The analysis is done mainly for the Balkan case and partly for the Iberian case.

Calculations of OPEX and CAPEX of accepted flexible resources in the Balkan case are given in the following text. The results of the OPF simulation, which was performed after the expansion of the grid to accepted candidates, were used for the analysis. OPEX for flexible load includes shifting and reduction costs which are obtained directly from OPF results, while OPEX for storage is obtained based on hourly injection (absorption) and nodal prices (LMPs) which are also part of OPF results. The following table provides an overview of OPEX and CAPEX of flexible resources in 2030, 2040, and 2050 for the Balkan regional case.

Table 4-1 – OPEX and CAPEX of flexible resources – Balkan RC

	2030	2040	2050
OPEX of flexible loads	3,061,875	8,431,852	202,982,126
Capex of flexible loads	15,000	10,809	15,061
OPEX of storage	2,232,135	200,513,056	496,778,512
Capex of storage	817,624	5,892,247	5,457,204

The following diagrams represent the OPEX and CAPEX of storage candidates selected in 2030, 2040, and 2050. For almost all storages OPEX is higher than CAPEX thus it is clear that investment decisions made by the GEP are justified from the financial aspect. The type of storage that has the greatest OPEX in 2030 is flow battery while in 2040 and 2050 those are hydrogen storage and LAES due to their high energy capacity. The hydrogen storage that has higher CAPEX than OPEX in 2030 is located in the area of very high generation curtailment and the investment decision made by the GEP is probably justified by significant curtailment reduction.

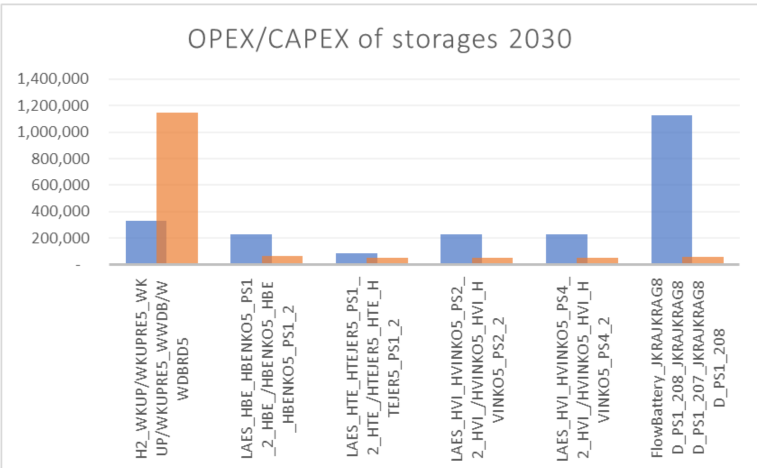

Figure 4-1 – OPEX and CAPEX of storages (Year 2030)

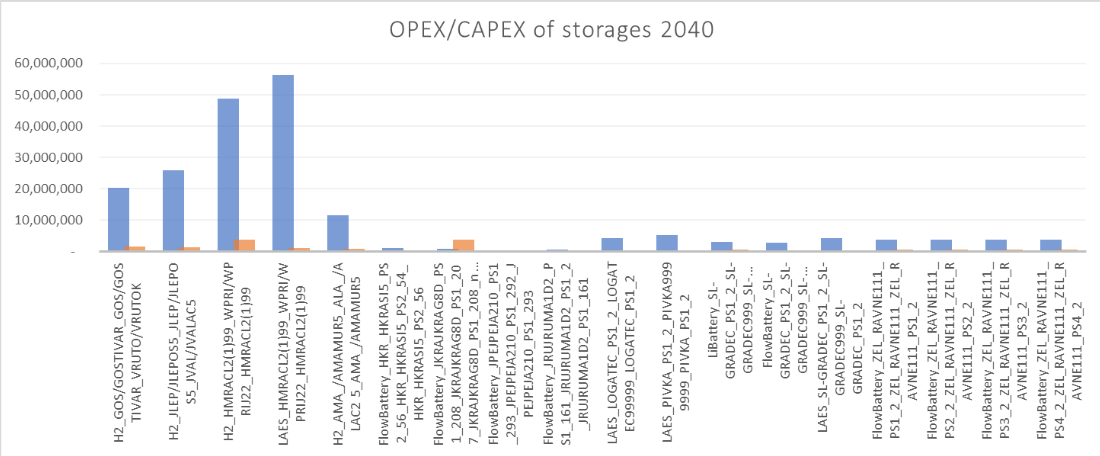

Figure 4-2 – OPEX and CAPEX of storages (Year 2040)

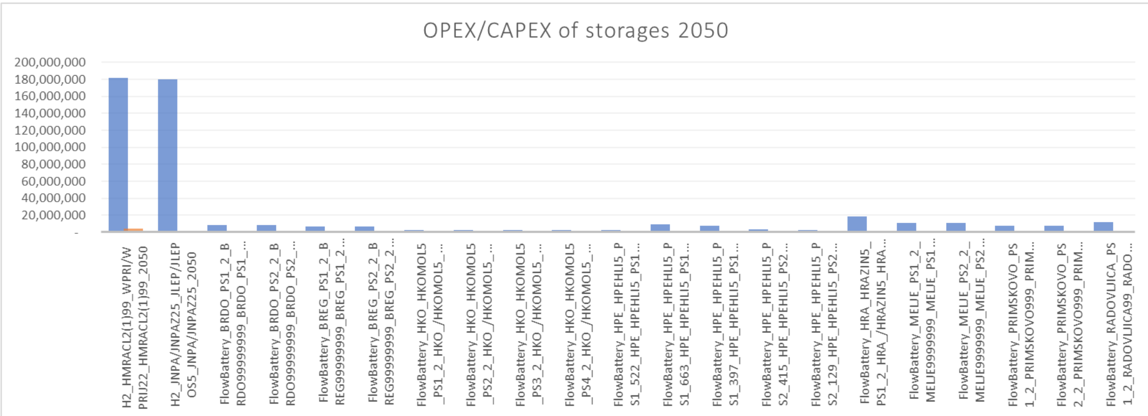

Figure 4-3 – OPEX and CAPEX of storages (Year 2050)

The following table shows the probability of accepting flexible candidates for each year. It can be noticed that as time progresses the percentage of acceptance grows for both flexible load and storage candidates.

Table 4-2 – Acceptance of flexible candidates in 2030, 2040 and 2050 – Balkan RC

	2030	**2040**	**2050**
% of acceptance of these candidates: Load	60.0	72.7	100
% of acceptance of these candidates: Storage	15.8	47.4	91.3

In order to determine the availability of the storage i.e. whether it has room for other services, the percentage of time during which the storage is used, as well as its average injection/absorption power during this time, is calculated and given in the following figures. In almost all cases the average power of sorages is above 80%. As for the usage time, in 2030 it doesn't go above 30% for any storage while in 2040 it's between 40% and 80%, and in 2050 between 60% and 100%.

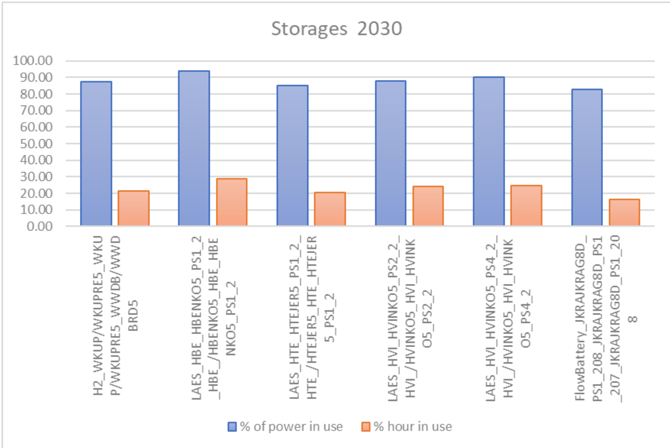

Figure 4-4 – Usage of storage capacities (Year 2030) – Balkan RC

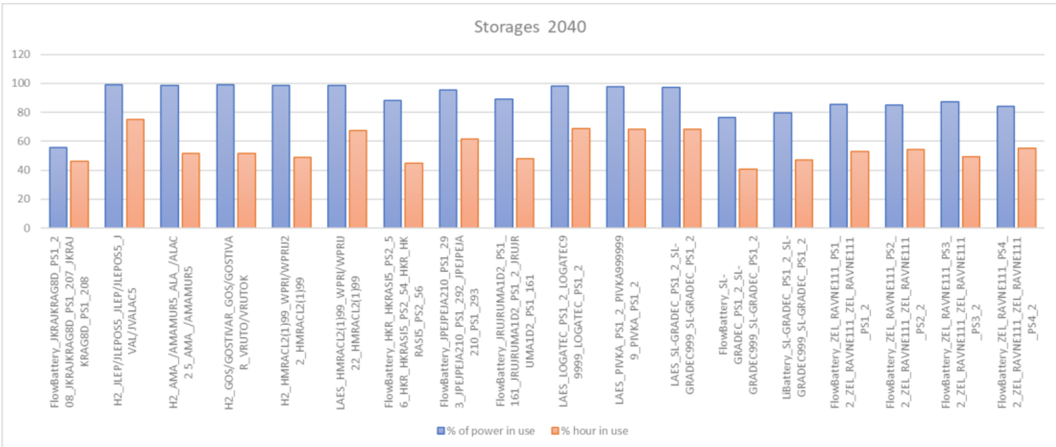

Figure 4-5 – Usage of storage capacities (Year 2040) – Balkan RC

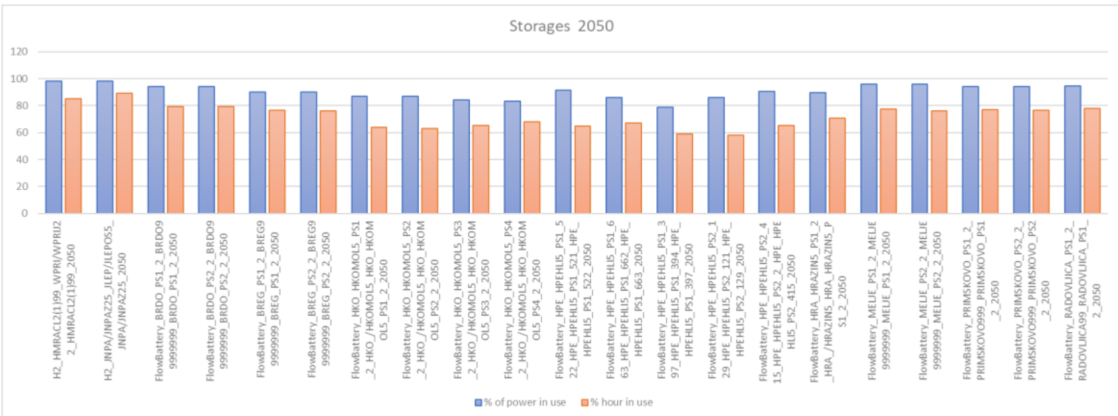

Figure 4-6 – Usage of storage capacities (Year 2050) – Balkan RC

Whether the engagement of flexible resources leads to the elimination of congestion can be observed through several specific cases in the distribution and transmission network, which are given below. The analysis of this detail for one case only (Balcan RC) has been considered sufficient for the discussion of this aspect. Its occurrence can be expected to be similar in other regional cases.

The optimal size of storages is calculated by the Pre-processor to provide enough service in such a way that it financially compensates the investment and it is not always a case that flexible resources try to eliminate congestion. For example, if the peak of congestion only occurs a couple of hours a year, and the next congestion is much lower and more frequent, it is sized to cover the most frequent one.

As an example of a distribution network, the network in the south of Serbia can be considered. Congestion occurs due to insufficient network capacity, which causes load curtailment. Figure 4-7 shows the evolution of the LM of the congested branch during 4 representative weeks, as well as the evolution of load curtailment, from which it can be concluded that congestion occurs in the 1st and 4th weeks. The proposed candidates for the solution to this congestion are the installation of a flow battery, the reinforcement of the existing line, and flexible demand. GEP recognizes that it is most profitable in this case to apply only flexible demand and that demand curtailment will be eliminated.

It can be seen that the congestion is almost completely eliminated by only the engagement of demand flexibility.

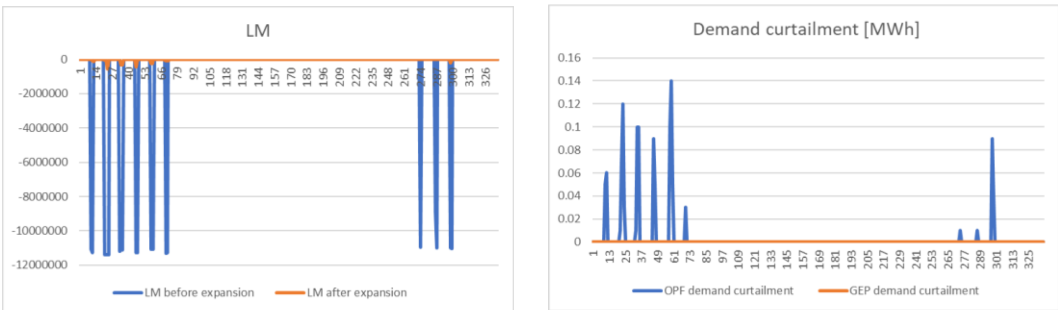

Figure 4-7: Evolution of LM and demand curtailment for congestion "JPREJPRESED_PS1_23_26 "

As an example of a flexible candidate for the transmission network, congestion on the interconnecting 220 kV transmission line between Bosnia and Herzegovina and Croatia (Mraclin - Prijedor) that occurs in 2040, is observed. For this congestion, the reinforcement of the existing line, the installation of hydrogen storage, and the installation of LAES storage were proposed. In Figure 4-8, the view of this area is enlarged, and the congested branch is marked. As profitable investments, GEP chose storages in substation Mraclin (Croatia), which considers hydrogen storage and LAES with the power rates of 3% of the capacity of the congested branch, and reinforcement of the existing 220 kV line Prijedor – Medjuric.

Figure 4-8: Congestion “AC_WPRI/WPRIJ22_HMRACL2(1)99” and proposed candidates

Figure 4-9 shows the evolution of LM for the first week before and after the expansion of the network, and Figure 4-10 shows the storage engagements for the same week as well as the nodal price (LMP) of the node in which storages are connected. The optimization process shows that the storages do not completely remove the congestion that occurs in the first part of the week. On the other side, storages perform arbitrage, i.e. they store the energy in hours of lower nodal prices (lower LMP) and inject it into the network in hours of higher prices (higher LMP) which makes the overall costs of the system lower.

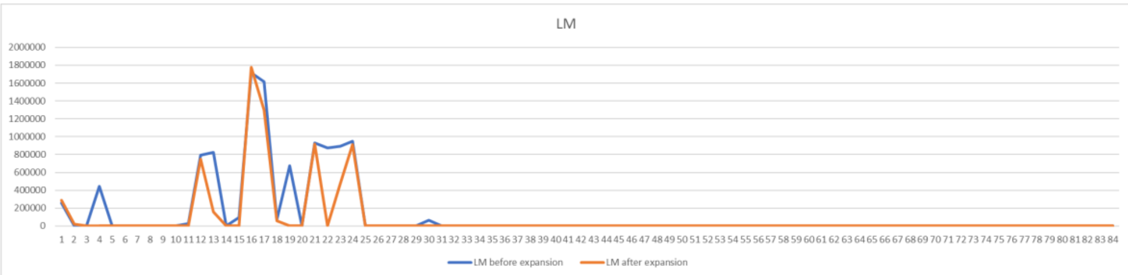

Figure 4-9: Evolution of LM for congested branch “AC_WPRI/WPRIJ22_HMRACL2(1)99 “

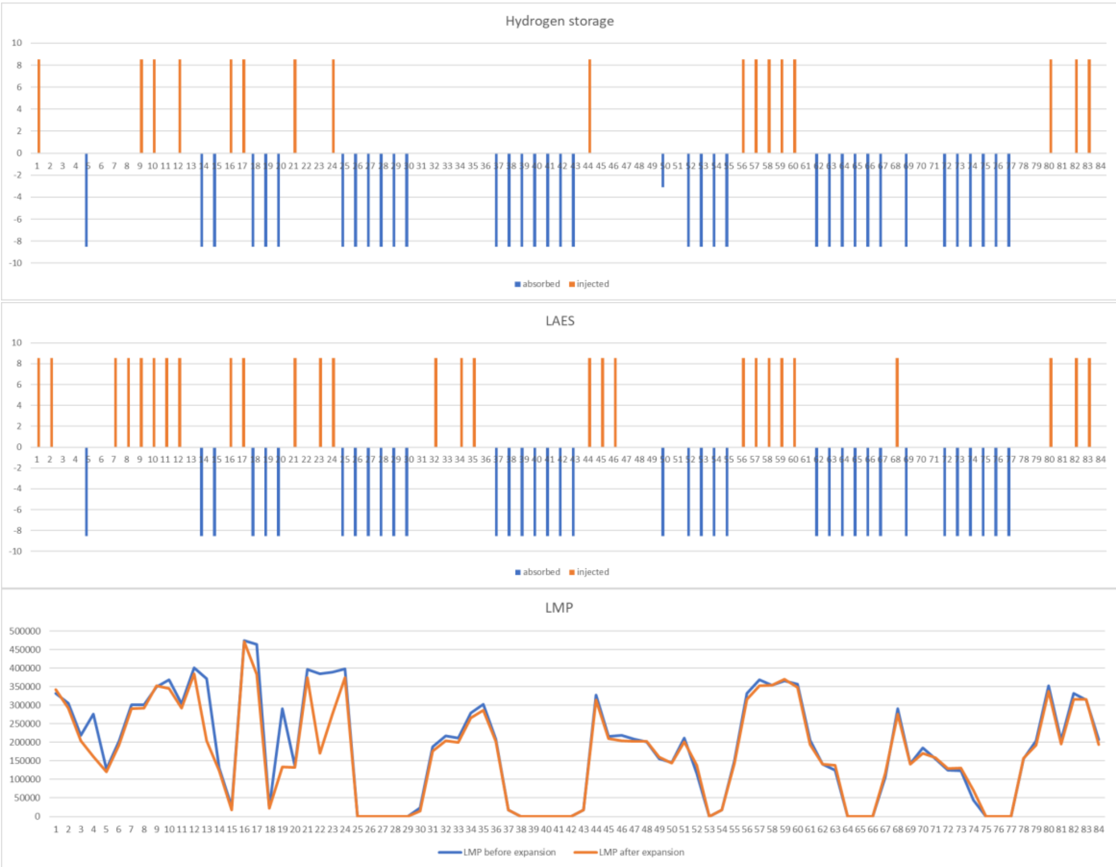

Figure 4-10: Storages performance and nodal price (LMP) for congestion "AC_WPRI/WPRIJ22_HMRACL2(1)99 "

As for the Iberian case, additional OPF calculations after the expansion of the network were not simulated. Therefore the nodal prices (LMPs) of the expanded network, which are needed for the calculation of OPEX of flexible resources, were not available. Because of this, nodal prices coming from the non-expanded OPF were used along with injections/absorptions of storages from GEP results. Based on this data, the exact value of OPEX cannot be obtained, but the cost of the congestion that is eliminated thanks to storage can be obtained. OPEX is, for sure, lower than that value.

The following table provides an overview of the OPEX (maximum possible for storages) and CAPEX of flexible resources in 2030, 2040, and 2050 for the Iberian case.

Table 4-3 – OPEX and CAPEX of flexible resources – Iberian RC

	2030	2040	2050
OPEX of flexible_loads	2,870,364	2,573,594	0
Capex of flexible_loads	9,000	5,000	0
OPEX of storage	63,089,037	6,749,325	332,744,621
Capex of storage	893,333	442,493	8,379,467

The following table shows the probability of accepting flexible candidates for each year. It can be noticed that as time progresses the percentage of acceptance for flexible load decreases and in 2050 its value is zero while for storages it increases and in 2050 its value is 100.

Table 4-4 – Acceptance of flexible candidates in 2030, 2040 and 2050 – Iberian RC

	2030	2040	2050
% of acceptance of these candidates: Load	27.27	23.81	0
% of acceptance of these candidates: Storage	33.33	40.00	100

As for the availability of storages for the provision of services other than congestion management, the percentage of time during which the storage is used, average injection/absorption power during this time, as well as average state of charge, are calculated and given in the following figures. It can be noticed that the active power exchange is used at 100% of the storage capacity in 2030. In most cases (not all of them) this means that congestion occurs. As expected, the number of hours in use rises from 40-60% in 2030 to 70-90% in 2040 and 2050 which means there is room for providing other services.

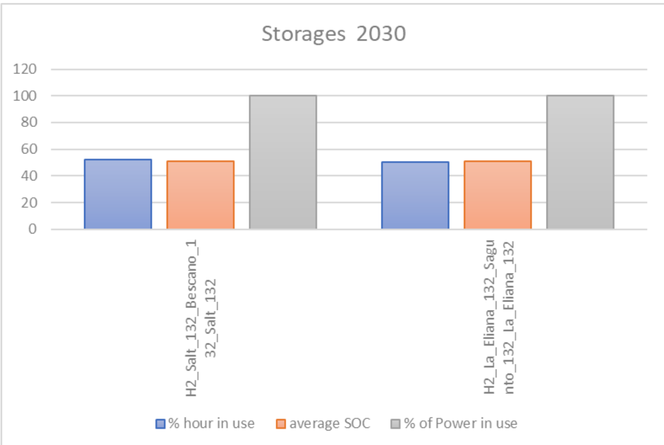

Figure 4-11 – Usage of storage capacities (Year 2030) – Iberian RC

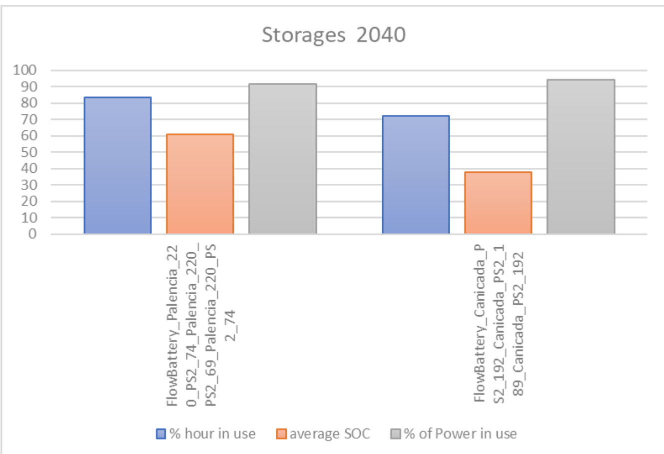

Figure 4-12 – Usage of storage capacities (Year 2040) – Iberian RC

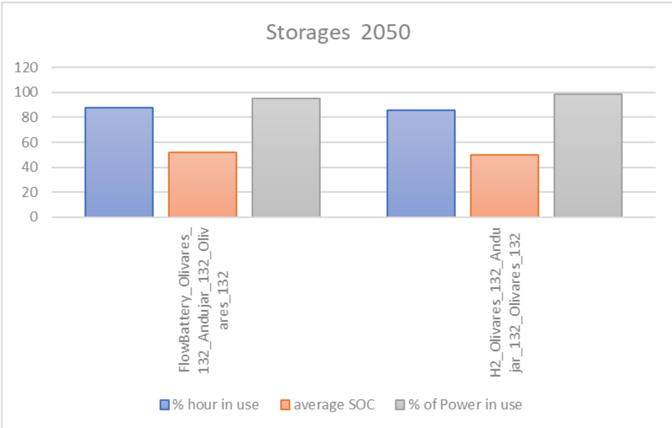

Figure 4-13 – Usage of storage capacities (Year 2050) – Iberian RC

5 Conclusions

These are the main conclusions derived from the validation that was carried out with the candidate pre-processor tool:

- The pre-processor does not work with specific requirements for every RC. Specific data of RCs could have been included in the SW as input (within the code), but this information was not available. Finding good quality input data is key, but it remains a challenge because many diverse technologies, scenarios, networks, etc. need to be considered.
- Since congestion is severe for all high-ranked branches, batteries are not proposed as a candidate in the Iberian case. This does not mean that batteries are not a good option for the network, but that they are not probably the best choice to cope with this type of congestions, where increasing the capacity of branches and transformers, plus using flexible loads, seems to be a better option. Battery storage might be a better option for shorter congestions and to provide other types of services to the network (e.g. ancillary).
- In the Balkan case, congestions that occur in the transmission network last longer, and therefore only hydrogen storages are proposed as they have high energy capacity.
- Flexible loads reduce the curtailed generation and load by shifting and reduction, which reduces the total cost of the system.
- Flexible resources are not sized to necessarily cover all congestions that occur. In the case of storage, the optimal size is calculated to provide enough service in such a way that it financially compensates the investment.
- The results we obtain are related to the assumptions that we take and the values we adopt in the methodology [1]. However, now that the planning process is launched step by step, the candidates proposed by the pre-processor or their characteristics, can be modified. Sensibility is a good approach to understand the impact of the main variables of the system, which are mainly, prices (of generation, demand curtailment, generation curtailment, environmental costs, etc.) and lifetime of technology.
- The pre-processor was adapted to accommodate to the new formats of planning tool and data, which were adopted to meet the challenges of the project: passing from M€ to €, modifying the cost of the lines, including environmental costs, modifying load flexibility compensation values, including distribution network identification number for T&D decomposition, adapting the formats to cope with the change in the planning procedures (e.g. number of years, hourly time step), etc. To increase efficiency, it is worth trying to plan developments in advance and to consider that, in R&D projects, modifications will arise, so developments should be prepared with that premise in mind.

6 References

[1] FlexPlan Deliverable, D2.3.
[2] FlexPlan Deliverable, D1.2.