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FlexPlan

Balkan RC workshop| 7th February 2023

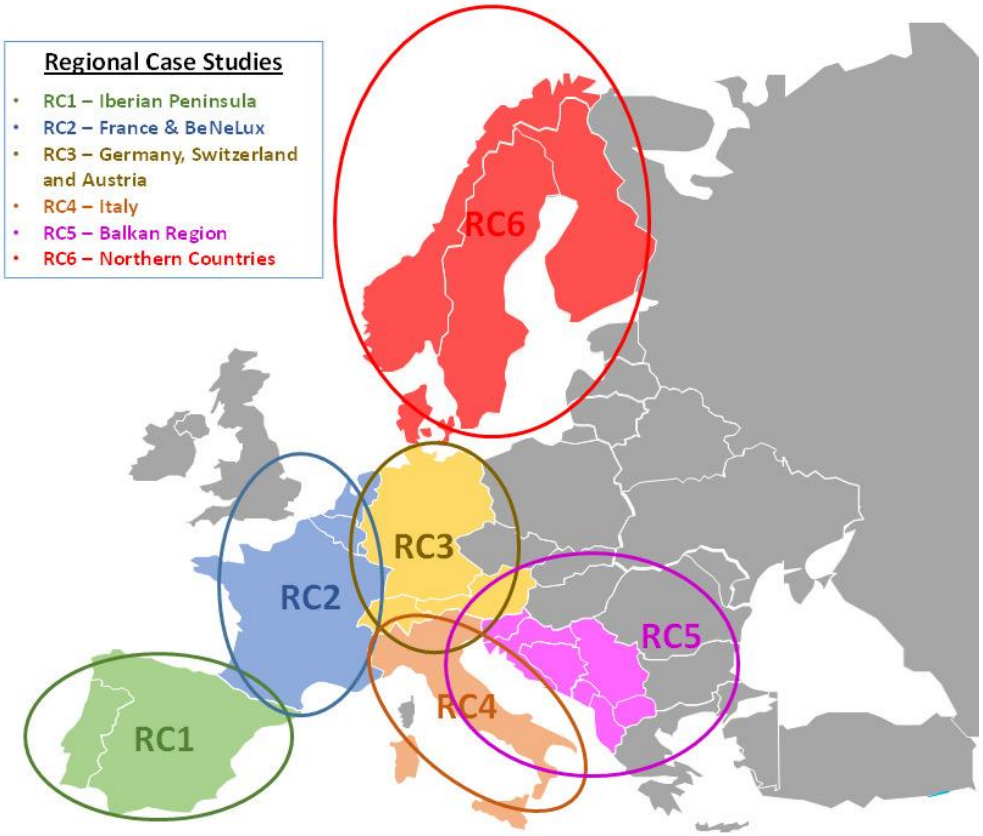
FlexPlan WP5 results

Balkan case

Boris Brdjanin
EKC

WP5 description and involved partners

- Objectives
  - Development of optimal regional grid architectures for years 2030, 2040 and 2050 for deployment of flexibility sources at transmission and distribution levels and using FlexPlan planning tool.
  - Demonstrate the tool through six different regional cases



Power system modeling
Transmission network model

FlexPlan

WP1 – Planning Tool Specification

WP2 – Storage and Flexibility Solutions
Storage and flexibility solutions (each target year) and location constrains

WP3 – Planning Tool
Planning Tool implemented will be applied to each regional case

WP4 – Pan European Scenarios
Scenarios / models for each regional use case (and three target horizons)

WP5 – M16-M33 – (WP Leader: R&D NESTER)

Task 5.1
Common modelling and procedures M16 – M19
(Task leader: RSE)

Task 5.2
Regional cases development M18 – M33
(1 Leader per Case)
Northern Countries - SINTEF
Iberian Peninsula - TECNALIA
Germany, Switzerland and Austria - TUDO
Italy - RSE
Balkan Region – EKC
France and Benelux – VITO? / KUL?

WP6 – Regulatory Analysis
Results of Six Regional Cases for three target horizons (2030, 2040, 2050)

Power system modeling
Transmission network model

FlexPlan

- **T5.1 – Common modelling and procedures**
  - Identification of required parameters for the **creation of synthetic distribution grid networks**
  - **Collection of environmental and costs** related **data** corresponding to the six regional cases, including plant specific data for pollutant emissions
  - **Adaptation of WP4 scenarios** data to correspond to **grid nodal level**, required to perform regional cases simulations
  - **Validation and adaptation of ENTSO-E European Transmission System model**, used as main dataset for transmission networks of five regional cases

- **T5.2 – Regional Cases development**
  - **Conversion and adaptation of Transmission systems** for in-house simulation by each one of the Regional Cases. As one example, this adaptation include the addition of **geographic location** of **all** existing **grid nodes**
  - Creation of **missing transmission and sub-transmission grid models**. Sub-transmission systems were missing in 5 out of 6 regional cases. The Northern Countries Regional Case had to built most of the transmission grid model as well from different data sources (e.g. TSOs, regulators, open source data)
  - Development and testing of **methodologies to create JSON files** (chosen format to communicate with planning tool)

Workflow JSON-Creation

FlexPlan

ENTSO-E grid data (models for 2025 in CGMES format)

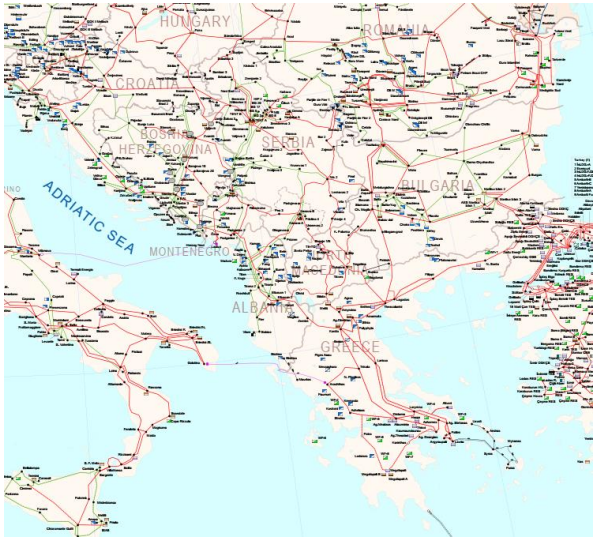
Scenario data (MILES) – WP4

JSON Files

Power system modeling

Transmission network model

ENTSO-E grid data (models for 2025 in CGMES format)



Balkan transmission network model:

- 1961 AC buses
- 3077 AC branches
- 1 DC branch

Transparency Platform

Power system modeling

Distribution network model

FlexPlan

Data provided from DiNeMo (Distribution Network Models) platform

↓

Synthetic distribution networks are generated

↓

Level of congestion is estimated for each distribution network

↓

Grid reduction performed in order to consider congested areas only

↓

Distribution network is integrated into the transmission model

https://ses.jrc.ec.europa.eu/dinemo

PDF

G. Viganò, M. Rossi, C. Michelangeli and D. Moneta, "Creation of the Italian Distribution System Scenario by Using Synthetic Artificial Networks" 2020 AEIT International Annual Conference, 2020, pp. 1-6

Balkan distribution network model:

- 1012 AC buses
- 1012 AC branches

Details of the scenario

Model of International Energy Systems

MILES (Model of International Energy System) is used in order to process ENTSO-E scenario data and to geographically allocate energy resources over the Balkan territory.

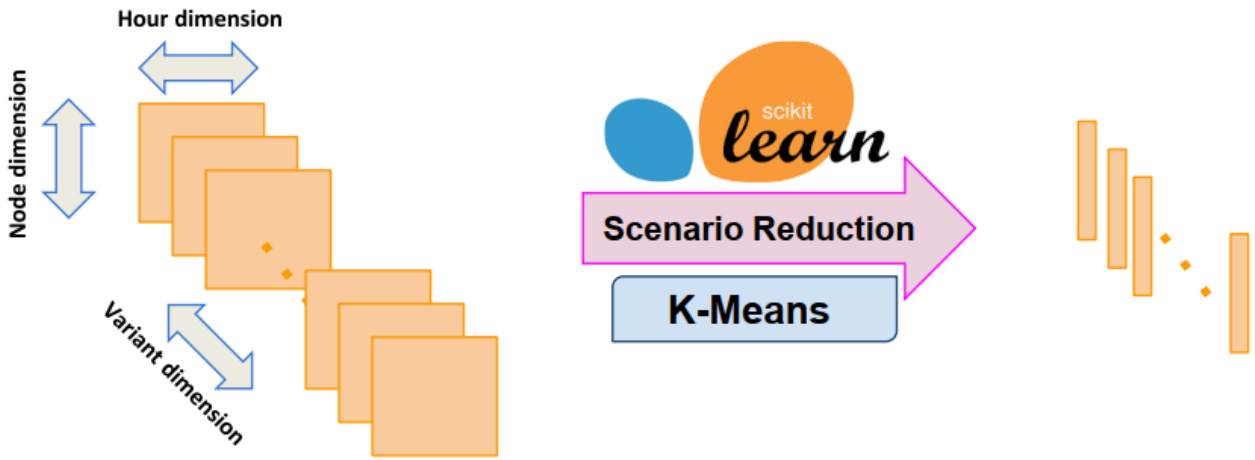
It uses:

- **ENTSO-e scenario data for 2030, 2040, 2050:**
  - **Distributed Energy scenario**
  - **Global Ambition scenario**
  - **National Trend scenario**

- **Commodity prices**
- **Balancing Reserves (2030)**
- **Net Transfer Capacities (2030)**

Details of the scenario

Scenario reduction



35 variants * **8760** hours

Time profiles of 35 climate variants for each decade (2030-40-50) and scenario (DE,GA,NT)

5 variants * **12** weeks * **168** hours

- 5 representative climate variants (with different probabilities)
- 12 representative weeks (one for each month of the year)
- Time resolution: 1 hour (168 time steps per week)

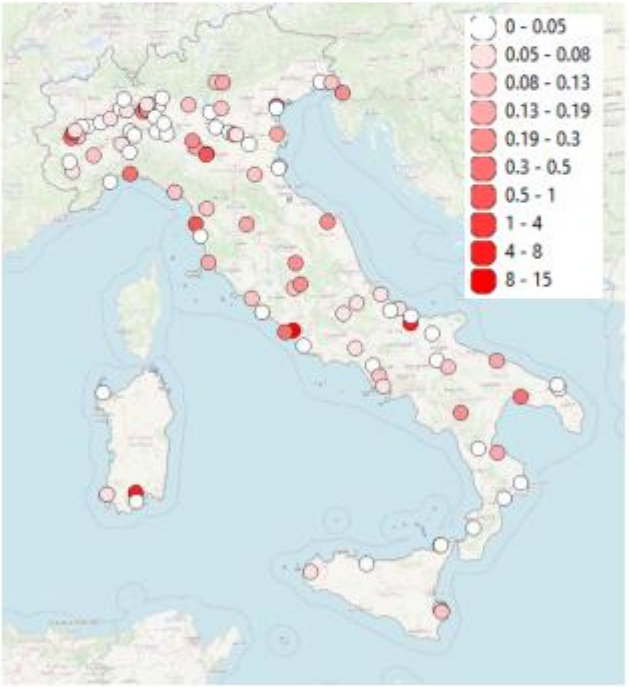
Details of the scenario

Environmental impact

FlexPlan

Health impact (YOLL/µg·m^{-3})
Cost (€/YOLL)
Reference production (MWh)

Air quality impact cost (€/MWh)



Impact areas around power plants (25 km radius)

Resident population

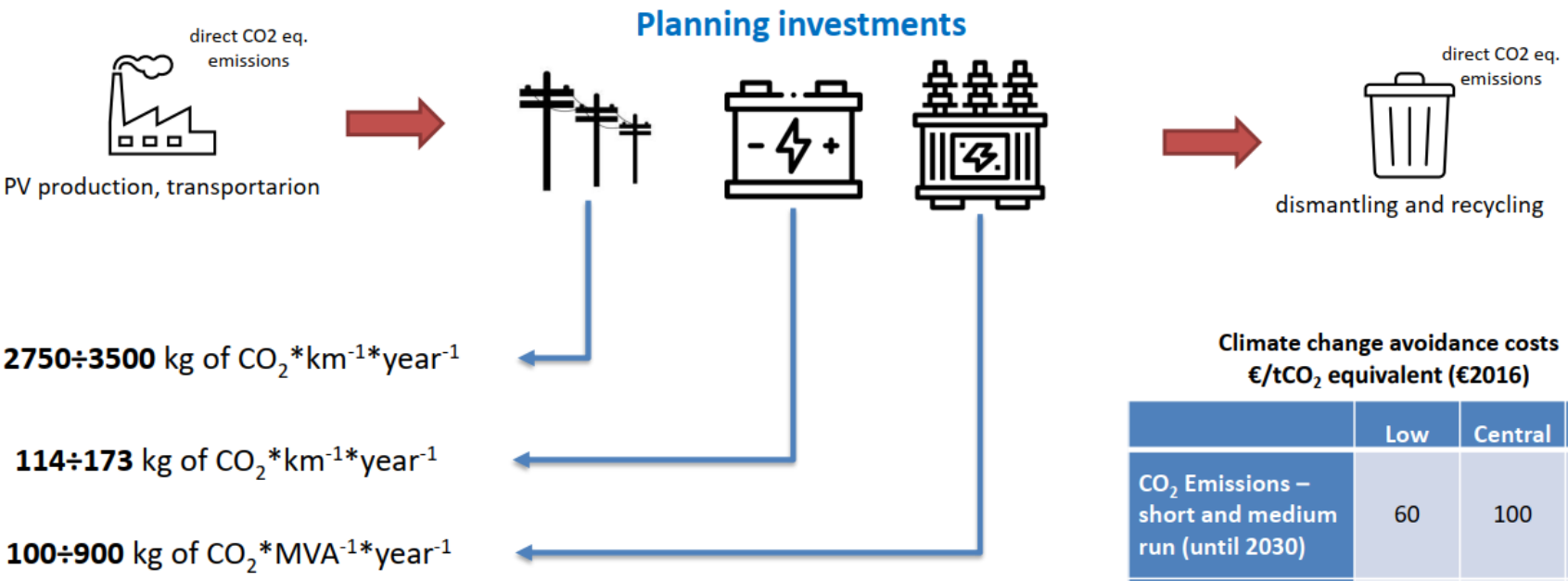
Weighting factor of individual power plant with respect to others

Pollutant concentration cumulative impact due to all generators, estimated with air quality simulations

Details of the scenario

Carbon footprint

FlexPlan



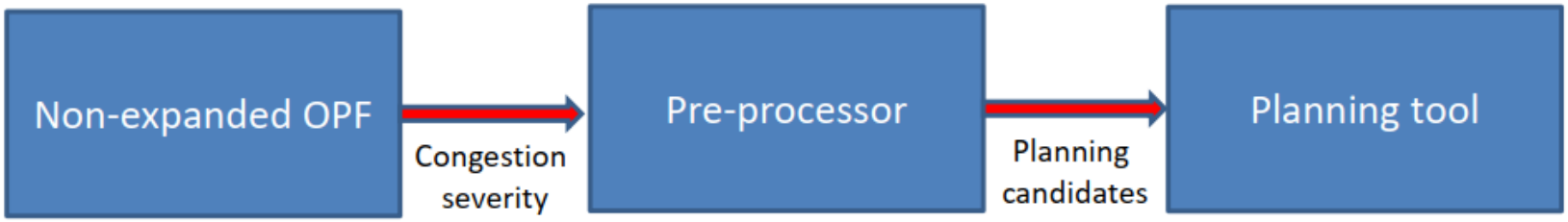
Climate change avoidance costs €/tCO_2 equivalent (€2016)

	Low	Central	High
CO_2 Emissions – short and medium run (until 2030)	60	100	189
CO_2 Emissions – long run (from 2040 to 2060)	156	269	498

Planning tool testing and model simplifications

FlexPlan

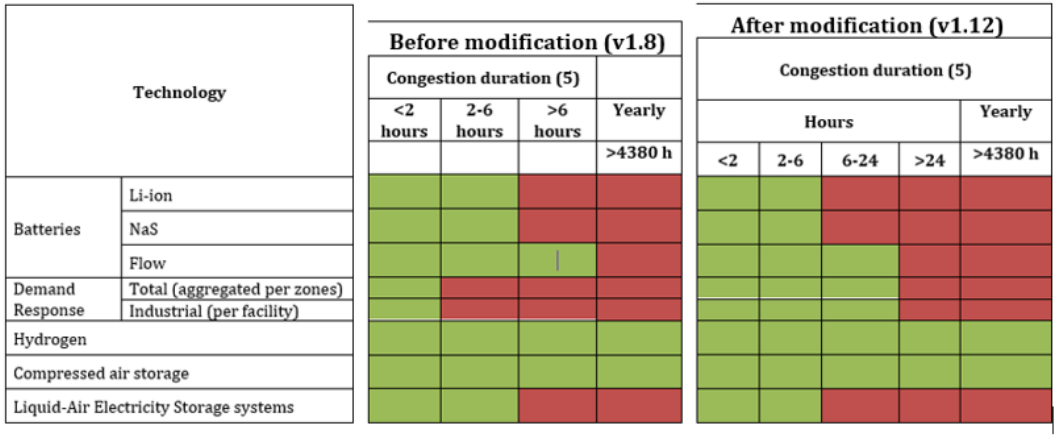
Grid Expansion Planning (GEP) process



- Role of the **non-expanded Optimal Power Flow**
- Simulation of the scenario and indication of the level of congestion for grid elements
- Role of **Preprocessor**
- Identification of potential asset investments aimed at solving congestion (with priorities depending on congestion severity – Lagrange Multipliers)
- Identification of nodes in which storage/demand flexibility can be beneficial for congestion management (using Locational Marginal Prices)
- Proposal of storage technology on the basis of characteristics of congestions and territory
- Role of **Planning tool**
- Returns the list of the candidates which minimizes the total costs (CAPEX+OPEX), and details on their behavior

Planning tool testing and model simplifications

Grid Expansion Planning (GEP) process



Batteries	ID	Size depending on branch rating			Maximum and minimum size per technology (MVA)					
		2030	2040	2050	2030		2040		2050	
		as % of the congested branch power rating			Min	Max	Min	Max	Min	Max
Li-ion batteries	LiBattery	2%	3%	4%	0.1	450*	0.1	700*	0.1	1000*
NaS batteries	NaSBattery	2%	3%	4%	1.2	220*	1.2	330*	1.2	440*
Flow batteries	FlowBattery	2%	3%	4%	0.01	600*	0.01	900*	0.01	1200*
Hydrogen	H2	2%	3%	4%	1.5	200*	1.5	300*	1.5	400*
Compressed air storage	CAES	2%	3%	4%	0.01	330*	0.01	330*	0.01	330*
Liquid-Air Electricity Storage systems	LAES	2%	3%	4%	0.3	100*	0.3	150*	0.3	200*

* Size extrapolated from the present available maximum size by cost factor for the corresponding years

Table 7-1 – Size of storage [3]

Planning tool testing and model simplifications

Grid Expansion Planning (GEP) process

Batteries	Cost								
	2030			2040			2050		
	CAPEX		OPEX	CAPEX		OPEX	CAPEX		OPEX
	€/kW	€/kWh	€/kWh	€/kW	€/kWh	€/kWh	€/kW	€/kWh	€/kWh
Li-ion	300	300	0.5% CAPEX	225	225	0.5% CAPEX	150	150	0.5% CAPEX
NaS	200	200	0.5% CAPEX	155	155	0.5% CAPEX	110	110	0.5% CAPEX
Flow	200	200	0.5% CAPEX	155	155	0.5% CAPEX	110	110	0.5% CAPEX

All costs were extrapolated from the present cost and future indicative cost in D2.2 [3]

Table 7-2 – Cost of batteries

Other storage	Cost					
	2030		2040		2050	
	CAPEX (€/kW)	OPEX (€/kWh)	CAPEX (€/kW)	OPEX (€/kWh)	CAPEX (€/kW)	OPEX (€/kWh)
Hydrogen	500	2% CAPEX	450	2% CAPEX	400	2% CAPEX
Compressed air storage	60	0.23	60	0.23	60	0.23
Liquid-Air Electricity Storage systems	175	0.5% CAPEX	135	0.5% CAPEX	95	0.5% CAPEX

Table 7-3 – Cost of other storage [3]

Planning tool testing and model simplifications

FlexPlan

Dealing with real-size power systems

The development of the planning procedure has been carried out in order to be able to manage:

- **Real/size power systems** with more voltage levels simultaneously (transmission, and distribution)
- **Multiple scenarios** to consider both variability of electricity demand and renewable power production (climatic variants)
- **Multiple target years**, to optimally select investments by considering planning impact over their entire lifetime

Planning tool testing and model simplifications

FlexPlan

Dealing with the limited time/hardware resources of FlexPlan

Even though the tools have been optimized to manage real-size systems, operating in many scenarios and climate variants, FlexPlan regional cases have been studied by applying some simplifications.

Reduced number of seasonal storages to 6
(instead of 12)

1-decade time horizon
(instead of 3)

100 planning candidates

Limited portion of Distribution Network
(10%)

Total processing time per reference year
3 ÷ 5 days

Relaxed optimality tolerance
(0.01% MIP-gap)

4 representative weeks
(instead of 12)

Reduced time resolution
(2-hour time blocks)

1 climate variant
(instead of 35)

Results of the planning process

Non-expanded OPF 2030

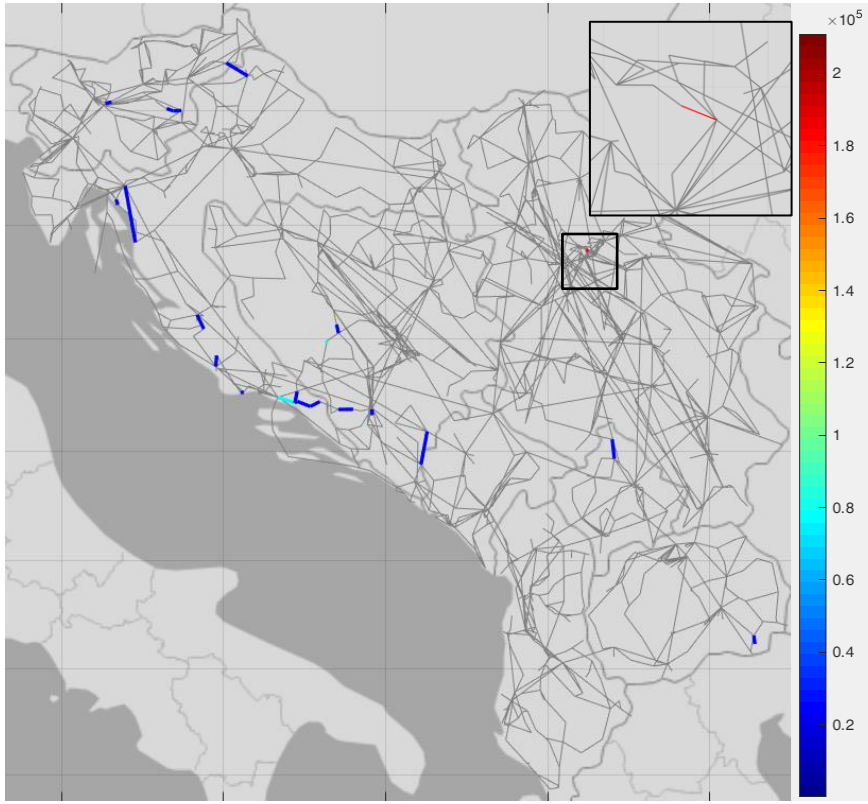
FlexPlan

Non-expanded OPF consists of a simulation of the energy dispatch model, including:

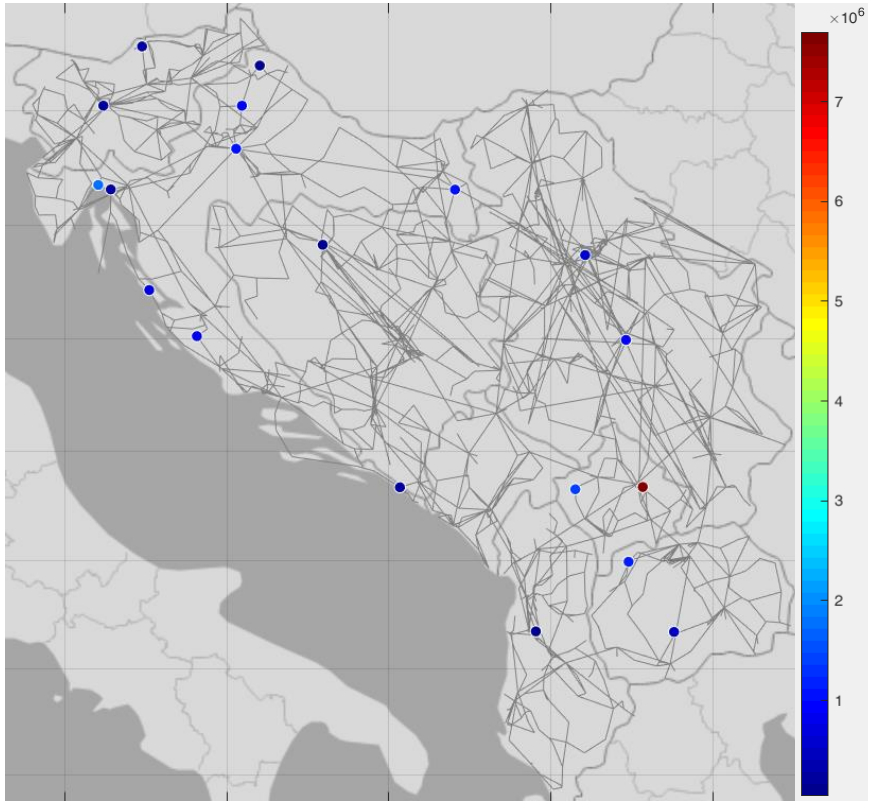
- Electricity generation:
- Dispatchable generator (fuel costs, environmental impact)
- Renewable energy sources (curtailment costs 0 €/MWh)
- Electricity transport and distribution
- Transmission network model (DC OPF)
- Distribution network model (linearized AC OPF)
- Electricity demand
- Loads (value of lost load 10 000 €/MWh)
- Electricity storage
- Pumped-hydro storage and water reservoirs (with injection/absorption efficiencies and water inflows)

Results of the planning process

Non-expanded OPF 2030



TRANSIMISISON ELEMENTS



DISTRUBUTION NETWORKS

- 63 branches with LM [€/p.u.] different than 0, annual average
- 23 of which are transmission branches (Melina-Senj and Bajina Basta – RH Bajina Basta 220 kV and the rest are 110 kV)

Results of the planning process

FlexPlan

Non-expanded OPF 2030

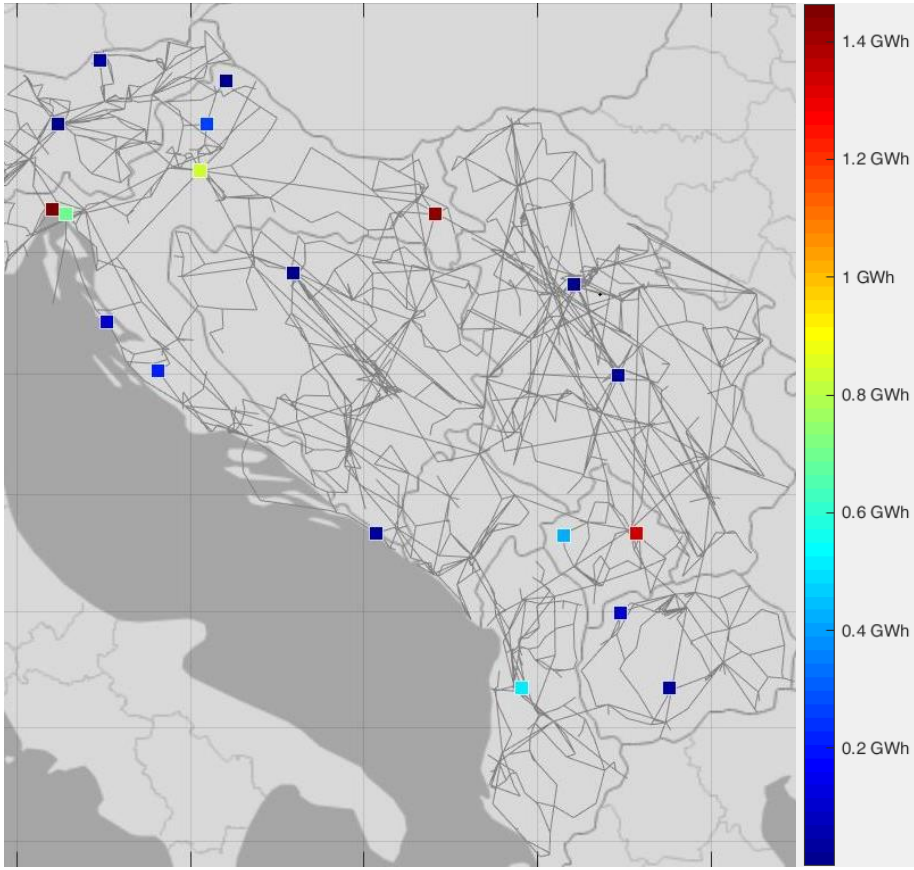
Branch	LM (max(abs)	LM (average (abs	No of congested hou	severity x ocurren
JPRJPRIS3D2_PS1_307_308	16870663.22	7739855.398	2033	15735126023
HKR_HKRASI5_PS2_2_54	16845006.26	3835649.14	1009	3870169982
JPEJPEJA210_PS1_2_19	16690252.16	3582465.738	942	3374682725
HPE_HPEHLI5_PS1_392_394	16663086.57	2640981.307	695	1835482008
HPE_HPEHLI5_PS1_521_522	16663086.57	2526956.196	665	1680425870
HPE_HPEHLI5_PS2_2_415	16663086.57	2424342.304	638	1546730390
ATI_ATIRA15_PS2_2_21	16672242.08	2216430.879	583	1292179202
HPE_HPEHLI5_PS1_2_662	16627960.21	1816057.583	478	868075524.7
HPE_HPEHLI5_PS2_118_121	16627960.21	1816057.583	478	868075524.7
JPEJPEJA210_PS1_2_292	16648754.82	1399303.453	368	514943670.8
ACJBG/JBGD1752-JBG/JBGD2351_1	2045254.423	211246.1255	2365	499597086.9
TETTETOVO 2_PS2_2_27	16679114.62	1156192.413	304	351482493.7
HVI_HVINKO5_PS1_trafo	16615938.06	1044875.66	275	287340806.6
HVI_HVINKO5_PS2_trafo	16615938.06	1044875.66	275	287340806.6
HVI_HVINKO5_PS3_trafo	16615938.06	1044875.66	275	287340806.6
HVI_HVINKO5_PS4_trafo	16615938.06	1044875.66	275	287340806.6
HMR_HMRACL5_PS1_trafo	16612049.14	1044736.755	275	287302607.5
HMR_HMRACL5_PS2_trafo	16612049.14	1044736.755	275	287302607.5
HMR_HMRACL5_PS3_trafo	16612049.14	1044736.755	275	287302607.5
HMR_HMRACL5_PS4_trafo	16612049.14	1044736.755	275	287302607.5
JKRAJKRAG8D_PS1_207_208	16620323.73	927270.009	244	226253882.2
HTE_HTEJER5_PS1_trafo	16601654.4	919263.3541	242	222461731.7
HBE_HBENKO5_PS1_trafo	16813360.6	764995.6298	201	153764121.6
HPA_HPAG 5_PS1_trafo	16595762.65	721519.419	190	137088689.6
ACHHE_/HHEKRA5-HZA_/HZAKUC5_1	462395.3421	104118.4239	1296	134937477.4
JBGJBGD16D1_PS2_2_57	16642334.03	608428.543	160	97348566.88
ACWKUP/WKUPRE5-WWDB/WWDBRD5_1	494439.0175	71945.20032	901	64822625.49
PRIPRILEP 2_PS1_2_143	16679133.96	414819.2075	109	45215293.62
ACHE BLANCA999-TEB999999999_1	326623.8955	41112.98962	747	30711403.24
ZEL_RAVNE111_PS1_trafo	16595538.4	227876.1025	60	13672566.15
ZEL_RAVNE111_PS2_trafo	16595538.4	227876.1025	60	13672566.15
ZEL_RAVNE111_PS3_trafo	16595538.4	227876.1025	60	13672566.15
ZEL_RAVNE111_PS4_trafo	16595538.4	227876.1025	60	13672566.15
ACWBUG/WBUGOJ5-WDVA/WDVAKU5_1	963035.5082	33984.37054	341	11588670.35
HKO_HKOMOL5_PS3_trafo	16596254.6	208911.7243	55	11490144.84
ACJLEP/JLEPOS5-JVAL/JVALAC5_1	301472.7646	13897.846	754	10478975.88
VIC_PS1_trafo	16593779.25	186083.2926	49	9118081.339
VIC_PS2_trafo	16593779.25	186083.2926	49	9118081.339
HKO_HKOMOL5_PS1_trafo	16596254.6	167144.6143	44	7354363.028
HKO_HKOMOL5_PS2_trafo	16596254.6	167144.6143	44	7354363.028
HKO_HKOMOL5_PS4_trafo	16596254.6	167144.6143	44	7354363.028
HKR_HKRASI5_PS1_trafo	16595579.04	167114.2678	44	7353027.782
ACHOB_/HOBROV5-HVE_/HVEBRU5_1	404327.3644	17890.20734	307	5492293.652
JBGJBGD1 D2_PS1_2_181	16619813.05	125489.3455	33	4141148.402
ATI_ATIRA15_PS1_135_136	16597353.65	125361.1378	33	4136917.548
ACHHE_/HHEKRA5-HVE_/HVEKAT5_1	325287.2151	10686.27033	297	3173822.289
ACJBB/JBBAST21-JRH/JRHBBA21_1	184169.1746	6572.138042	411	2701148.735
ACHIM_/HIMOTS5-HZA_/HZAGVO5_1	606803.8044	10127.36338	176	1782415.954
ACHE BLANCA999-SEVNICA99999_1	29323.3571	2851.586812	599	1708100.5
ACHHE_/HHEKRA5-HVE/HVELUKOV_1	58590.5653	2624.997515	446	1170748.892
ACHBI_/HBILIC5-HVE_/HVEGLA5_1	344687.3637	7938.432612	147	1166949.594
ACHVE_/HVEKAT5-HZA_/HZAGVO5_1	399101.3509	2504.05465	209	523347.4219
ACWBIL/WBILEC5-WGAC/WGACKO5_1	265100.0671	4692.368045	105	492698.6448
WBLUWBLUK45_PS1_2_158	16597556.79	41797.87654	11	459776.6419
HCA_HCAKOV5_PS1_trafo	16595531.76	41792.77686	11	459720.5455
HCA_HCAKOV5_PS2_trafo	16595531.76	41792.77686	11	459720.5455
ACHJE_/HJELIN5-HTR_/HTROGI5_1	270569.077	3533.364373	67	236735.413
ACHCR_/HCRIKV5-HHE_/HHEVIN5_1	345021.473	2001.955024	84	168164.222
ACVALANDOVO999-VEC BOGDANCI_1	263600.3826	769.7287745	33	25401.04956
ACHMELIN2(1)99-HSE_/HSENJ 2_1	7414.7617	126.3025792	132	16671.94046
ACWGRU/WGRUDE5-WSBR/WSBRU5_1	283735.2348	1003.058461	16	16048.93537
ACHNE_/HNEDEL5-HE FORMIN999_1	466130.9236	1173.864505	11	12912.50956
ACPOLJE9999999-TETOL9999999_1	34134.448	107.0593559	30	3211.780677
ACWMOS/WMOST15-WMOS/WMOST25_1	3814.3748	9.605797344	11	105.6637708

Results of the planning process

Non-expanded OPF 2030

- All demand curtailments occur in distribution network.
- Given that the costs of demand curtailment are 10,000 €/MWh, this leads to the fact that the congestions in these networks are much higher compared to those in the transmission network and therefore they are a higher priority for solving.

- The congestions in distribution networks geographically coincide with the locations of demand curtailment.

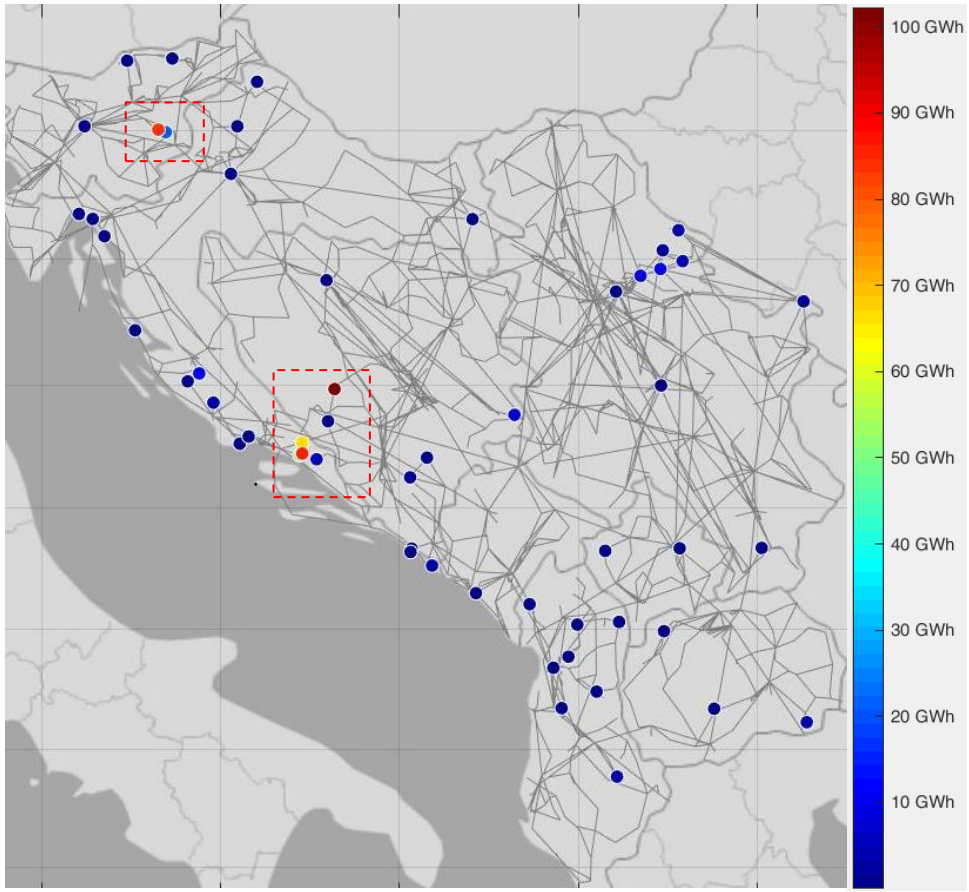


Results of the planning process

Non-expanded OPF 2030

- All generation curtailments occur for RoR, solar and wind power plants that are connected to transmission, mostly 110 kV and couple of them to 220 and 400 kV voltage level.
- Generation curtailment is more widespread and much larger.

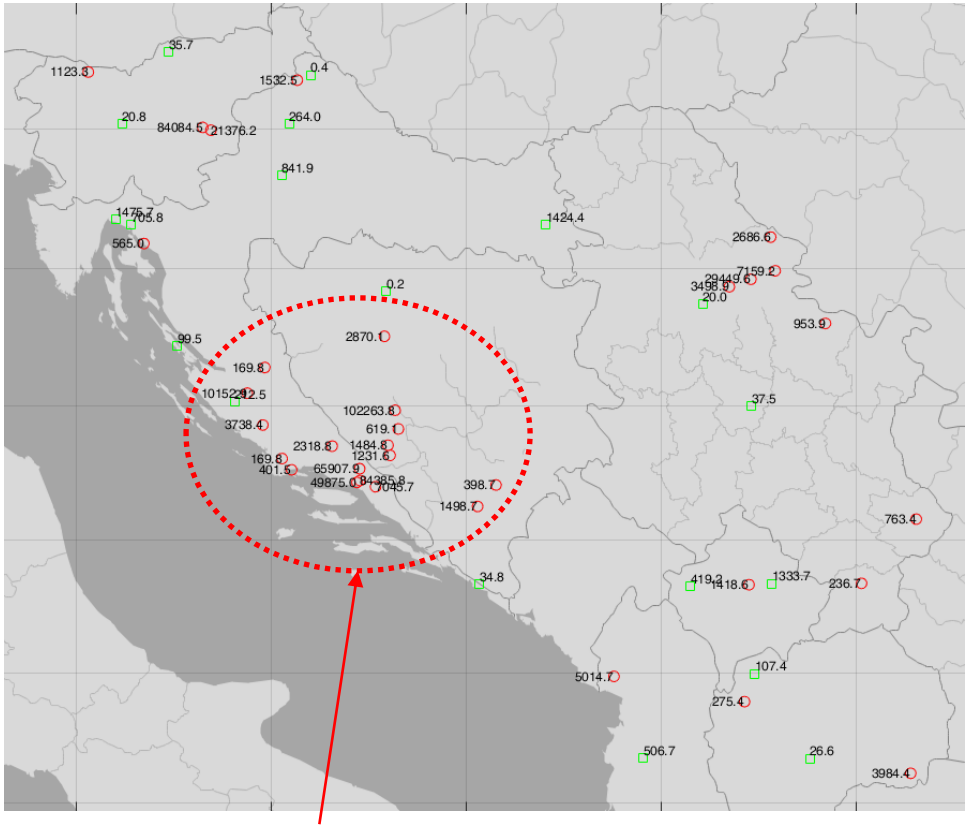
- Two areas with the largest generation curtailment, one in the western part and the other in the northwestern part of the region
- These areas coincide geographically with the highest congestions in the transmission network.
- Generation curtailment in the western area accounts for about 60%, while generation curtailment in the northwestern area accounts for about 20% of the total generation curtailment of the region.



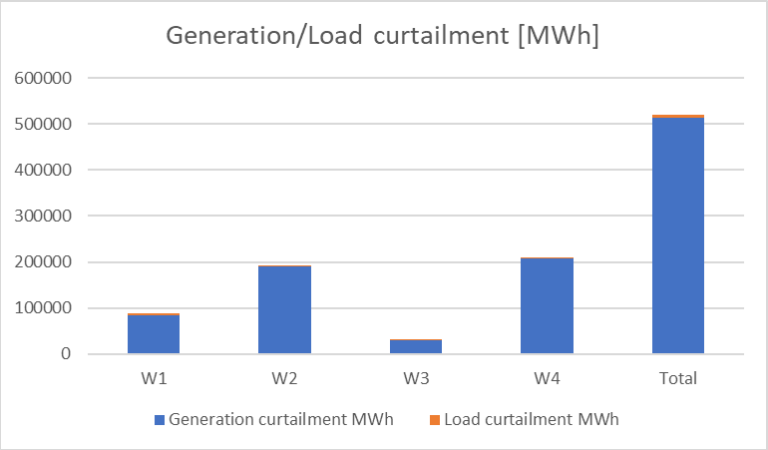
OPF results 2030

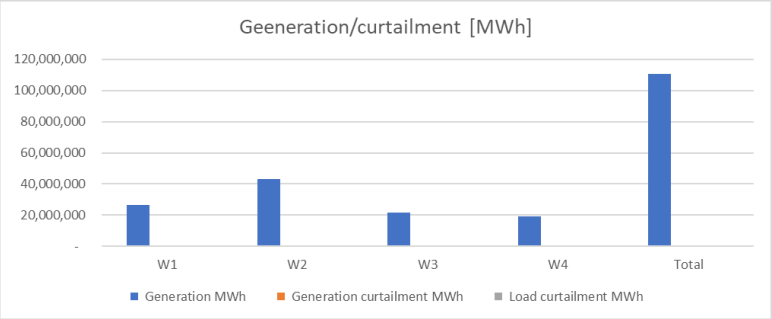
FlexPlan

- The figure shows annual values of curtailment in MWh.



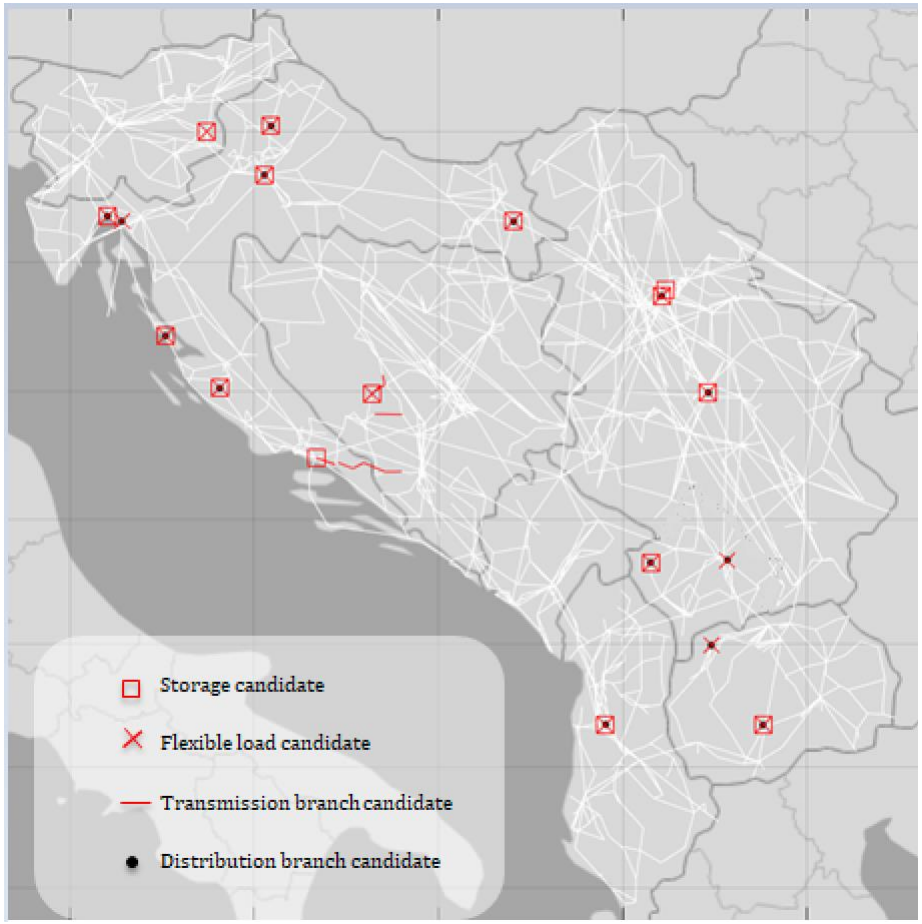
About 60% of total generation curtailment





Results of the planning process

Pre-processor results 2030

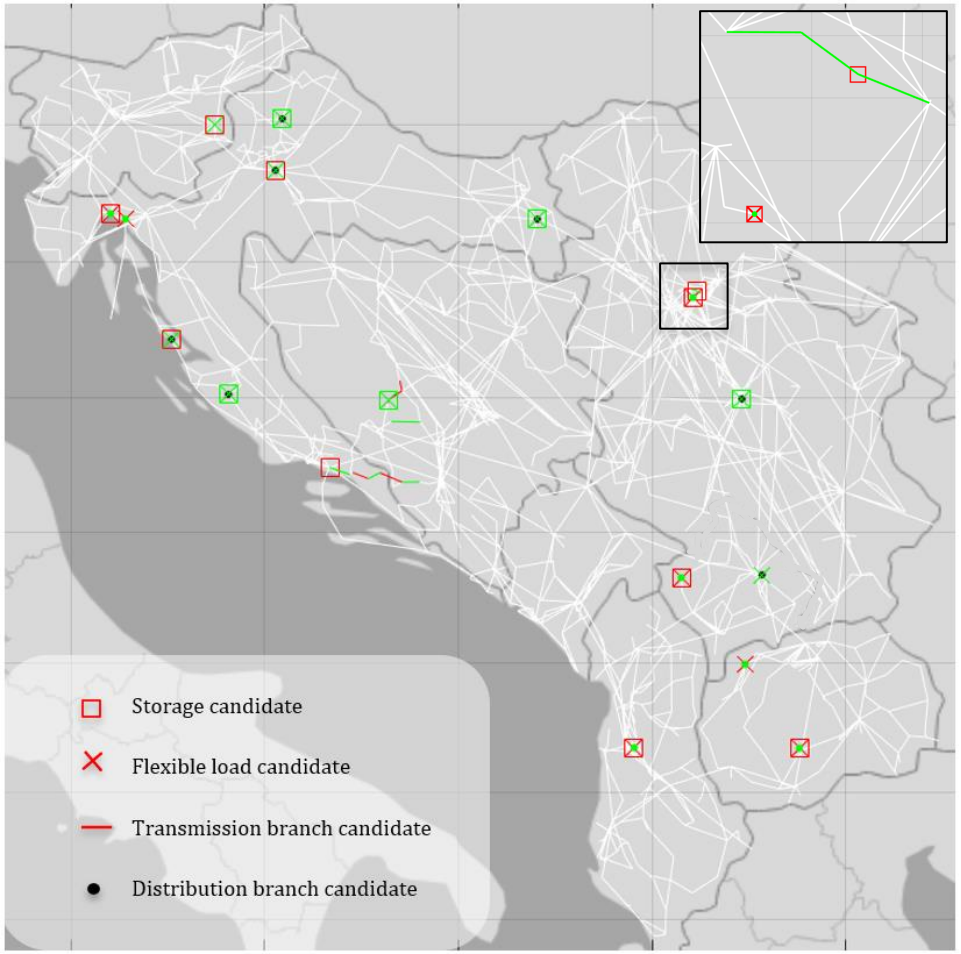


- As for the Pre-processor results, it was agreed that the number of candidates proposed by it should be limited to 100.
- The number of congestions that were handled was lower than 100, because some congestions had a larger number of proposed candidates.

Results of the planning process

FlexPlan

GEP results 2030



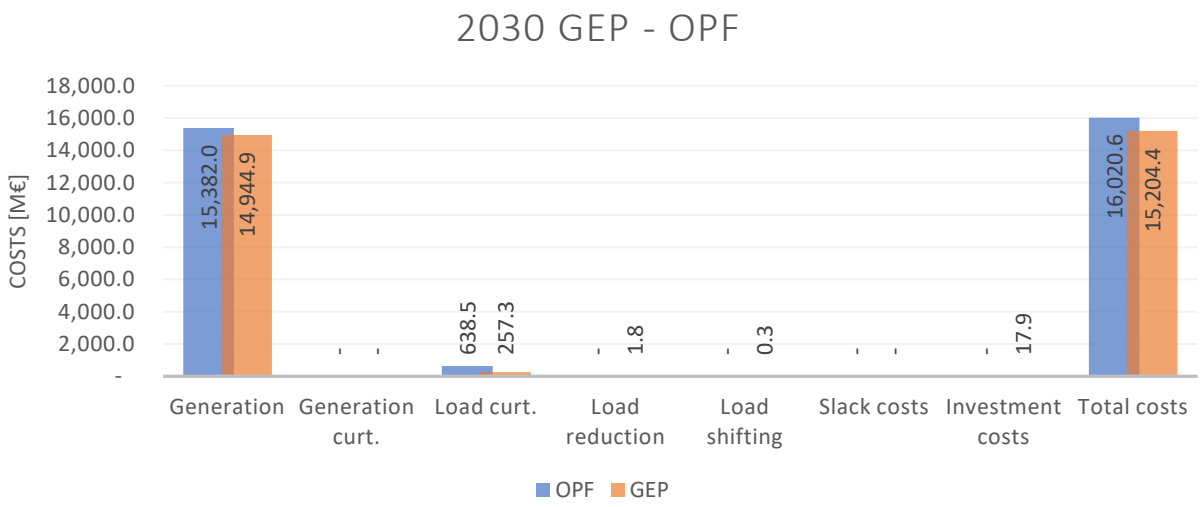
No.	Branch	Type	Congestion duration	Storage candidate				Branch candidate	Flexible load candidate
				H2	Flow	Li-ion	LAES		
1	JPRJPRIS3D2_PS1_307_308	Line	9					×	✓
2	HKR_HKRASI5_PS2_2_54	Line	9					✓	×
3	JPEJPEJA210_PS1_2_19	Line	8					✓	×
4	HPE_HPEHLI5_PS1_392_394	Line	8		×			✓	×
5	HPE_HPEHLI5_PS1_521_522	Line	8		×			×	
6	HPE_HPEHLI5_PS2_2_415	Line	8					×	
7	ATI_ATIRA15_PS2_2_21	Line	7		×			✓	×
8	HPE_HPEHLI5_PS1_2_662	Line	7		×			✓	×
9	HPE_HPEHLI5_PS2_118_121	Line	7		×			✓	×
10	JPEJPEJA210_PS1_2_292	Line	4		×			✓	×
11	**ACJBG/JBGD1752-JBG/JBGD2351_1**	Line	29	×				✓	
12	TETTETOVO_2_PS2_2_27	Line	5					✓	×
13	HVI_HVINKO5_PS1_trafo	Transformer	3		×			×	✓
14	HVI_HVINKO5_PS3_trafo	Transformer	3		×			×	✓
15	HVI_HVINKO5_PS2_trafo	Transformer	3		×	×	✓	×	✓
16	HVI_HVINKO5_PS4_trafo	Transformer	3		×	×	✓	×	✓
17	HMR_HMRACL5_PS1_trafo	Transformer	3		×	×		×	✓
18	HMR_HMRACL5_PS2_trafo	Transformer	3		×	×		×	✓
19	HMR_HMRACL5_PS3_trafo	Transformer	3		×	×		×	✓
20	HMR_HMRACL5_PS4_trafo	Transformer	3		×	×		×	✓
21	JKRAJKRAG8D_PS1_207_208	Line	3		✓			×	✓
22	HTE_HTEJER5_PS1_trafo	Transformer	3		×	×	✓	×	✓
23	HBE_HBENKO5_PS1_trafo	Transformer	3		×	×	✓	×	✓
24	HPA_HPAG5_PS1_trafo	Transformer	2		×	×		×	✓
25	**ACHHE_/HHEKRA5-HZA_/HZAKUC5_1**	Line	32	×				✓	
26	JBGJBGD16D1_PS2_2_57	Line	2		×			✓	×
27	**ACWKUP/WKUPRE5-WWDB/WWDBRD5_1**	Line	26	✓				×	
28	PRIPRILEP2_PS1_2_143	Line	4		×			✓	×
29	**ACHE_BLANCA999-TEB999999999_1**	Line	5	×	×				✓
30	ZEL_RAVNE111_PS1_trafo	Transformer	1						
31	ZEL_RAVNE111_PS4_trafo	Transformer	1						
32	**ACWBUG/WBUGOJ5-WDVA/WDVAKU5_1**	Line	5					×	
33	**ACJLEP/JLEPOS5-JVAL/JVALAC5_1**	Line	10						
34	ZEL_RAVNE111_PS2_trafo	Transformer	1						
35	ZEL_RAVNE111_PS3_trafo	Transformer	1						
36	VIC_PS1_trafo	Transformer	1						
37	VIC_PS2_trafo	Transformer	1						
38	HKO_HKOMOL5_PS1_trafo	Transformer	2						
39	HKO_HKOMOL5_PS2_trafo	Transformer	2						
40	HKO_HKOMOL5_PS3_trafo	Transformer	2						
41	HKO_HKOMOL5_PS4_trafo	Transformer	2						
42	HKR_HKRASI5_PS1_trafo	Transformer	2						
43	**ACHOB_/HOBROV5-HVE_/HVEBRU5_1**	Line	23						
44	ATI_ATIRA15_PS1_135_136	Line	1						
45	**ACHHE_/HHEKRA5-HVE_/HVEKAT5_1**	Line	3						
46	**ACJBB/JBBAST21-JRH/JRHBBA21_1**	Line	7						
47	**ACHIM_/HIMOTS5-HZA_/HZAGVO5_1**	Line	3					✓	
48	**ACHE_BLANCA999-SEVNICA99999_1**	Line	5						
49	**ACHHE_/HHEKRA5-HVE/HVELUKOV_1**	Line	27						
50	**ACHBI_/HBILIC5-HVE_/HVEGLA5_1**	Line	13						
51	**ACHVE_/HVEKAT5-HZA_/HZAGVO5_1**	Line	4					×	
52	**ACWBIL/WBILEC5-WGAC/WGACKO5_1**	Line	5						
53	WBLUWBLUK45_PS1_2_158	Line	1						
54	HCA_HCAKOV5_PS1_trafo	Transformer	1						
55	HCA_HCAKOV5_PS2_trafo	Transformer	1						
56	**ACHJE_/HJELIN5-HTR_/HTROGI5_1**	Line	3						
57	**ACHCR_/HCRIKV5-HHE_/HHEVIN5_1**	Line	5						
58	**ACVALANDOVO999-VEC BOGDANCI_1**	Line	1						
59	**ACHMELIN2(1)99-HSE_/HSENJ2_1**	Line	4						
60	**ACWGRU/WGRUDE5-WSBR/WSBRIJ5_1**	Line	1					✓	
61	**ACHNE_/HNEDEL5-HE FORMIN999_1**	Line	1						
62	**ACPOLJE9999999-TETOL9999999_1**	Line	1						
63	**ACWMOS/WMOST15-WMOS/WMOST25_1**	Line	1						

Results of the planning process

GEP results 2030

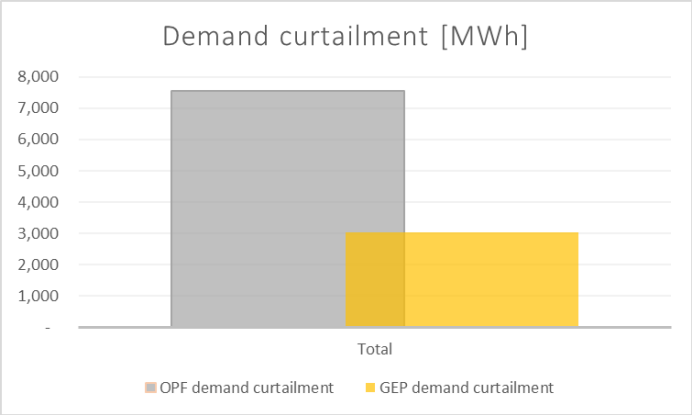
- The GEP process solves a mixed-integer optimization problem aimed at minimizing the total expenditure (CAPEX+OPEX) of the system.

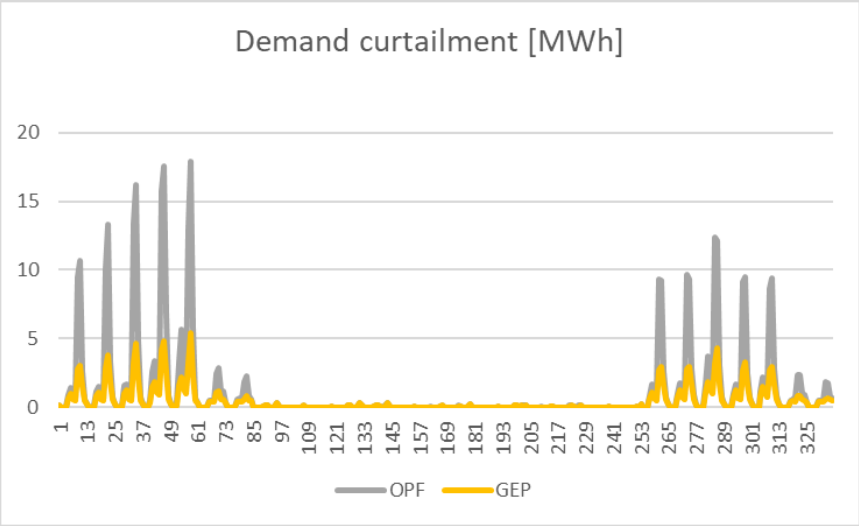
Description of the candidates (Year 2030)					
Type	AC Branch	Transformer	Storage	Flexibility load	Total
Number of candidates	37	0	38	25	100
Investment decisions	7 (Transmission) 10 (Distribution)	0 (Transmission) 0 (Distribution)	1 (H2) 1 (Flow Battery) 0 (Li Battery) 4 (LAES)	15	38
Investment rejected	5 (Transmission) 15 (Distribution)	0 (Transmission) 0 (Distribution)	3 (H2) 20 (Flow Battery) 9 (Li Battery) 0 (LAES)	10	62
Investment costs	17,086,360	0	817,624	15,000	17,918,985

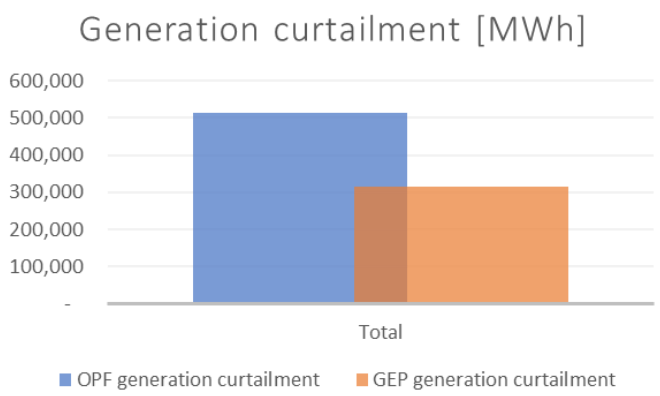


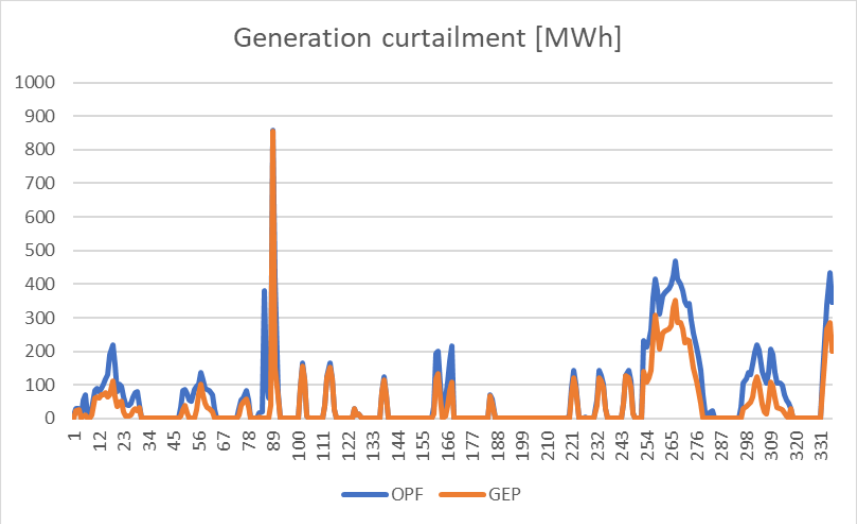
Results of the planning process

GEP results 2030



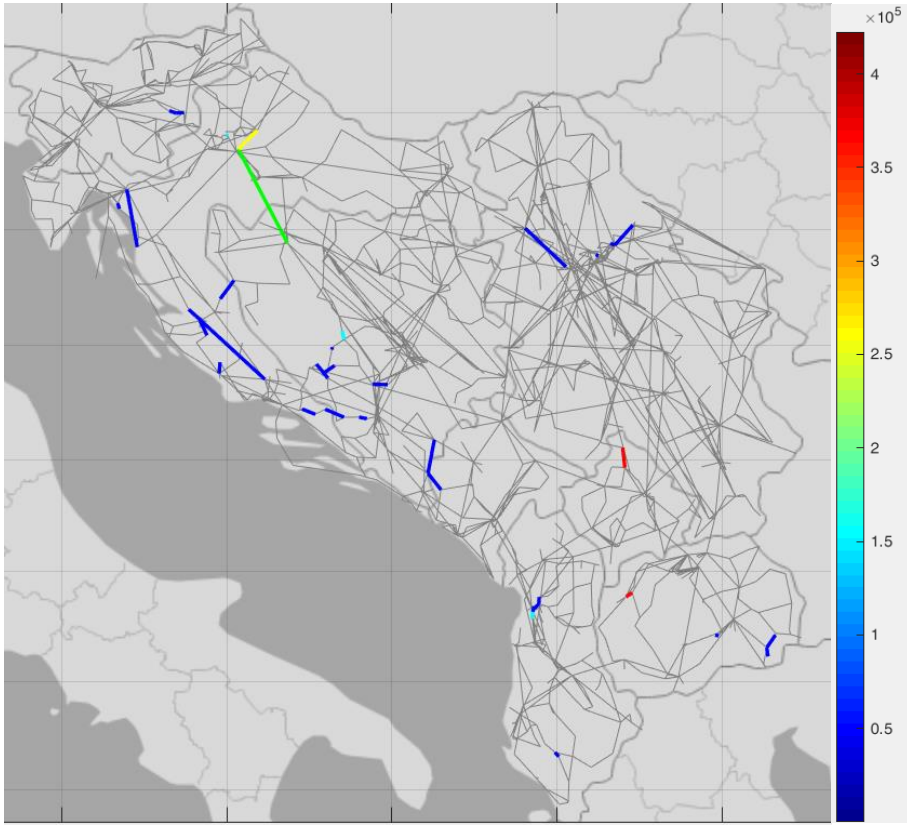


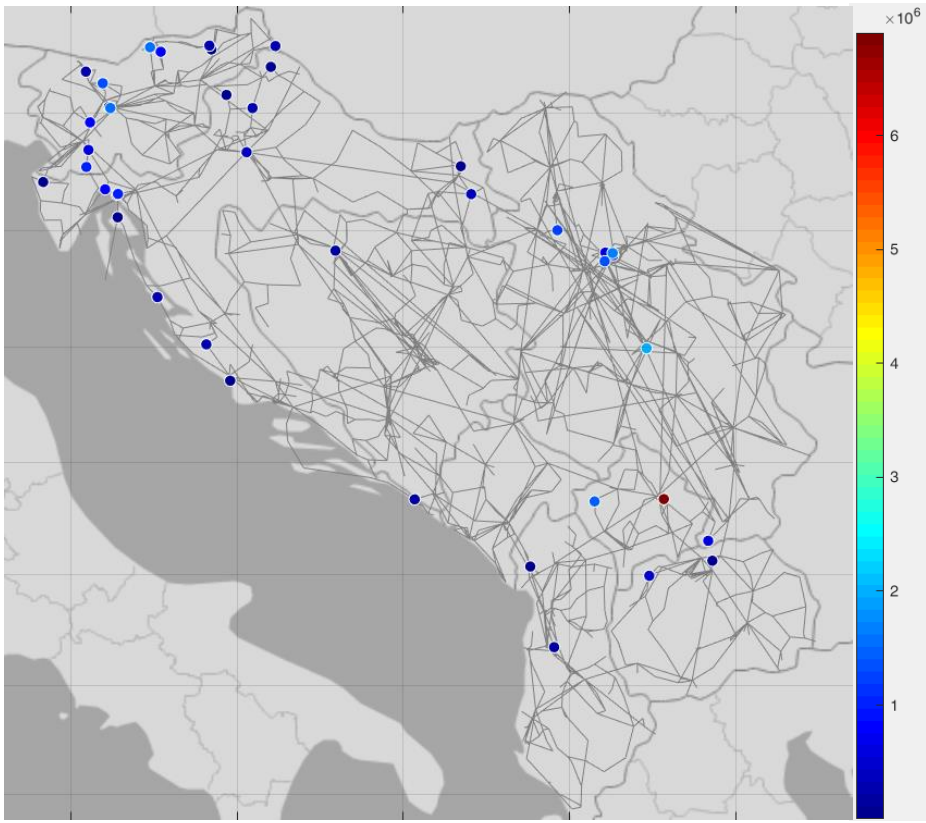




Results of the planning process

Non-expanded OPF 2040





- 109 branches with LM different than 0, annual average
- Due to the limitation of the number of candidates to 100, congestions in the transmission network were treated less in 2030 compared to congestions in distribution, and for this reason, some of them will be repeated in 2040.

Results of the planning process

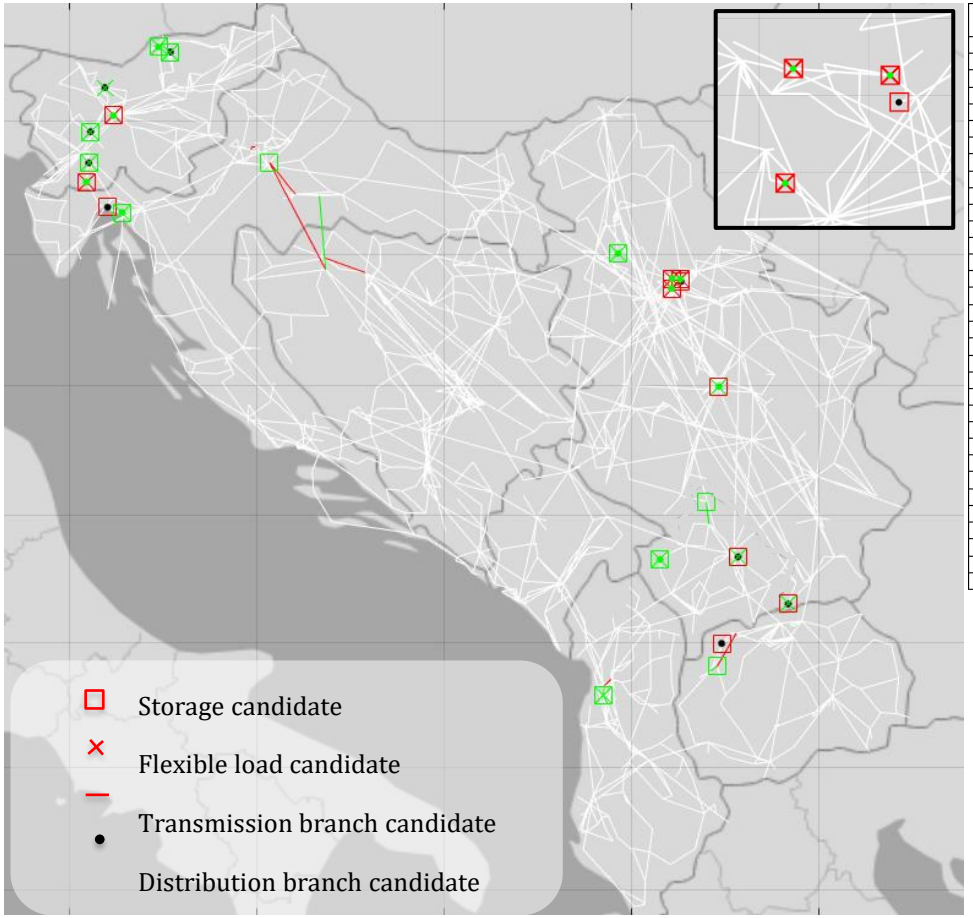
Non-expanded OPF 2040

- Demand curtailment occurs in 114 nodes, out of which 11 belong to 110kV transmission network, and the rest is in distribution network.
- 82% of annual demand curtailment still occurs in transmission.
- Demand curtailment occurs due to lack of capacity in distribution and transmission networks

- 2040 differs the most in that renewable energy sources are also distributed across distribution networks, while in 2030 they were all large-scale power plants connected to the transmission.
- Because of that, generation curtailment occurs in distribution as well, but it is still the most prevalent in the transmission level with a share of 93% of the total generation curtailment.

Results of the planning process

GEP and Pre-processor results 2040



No.	Branch	Type	Congestion duration	Storage candidate				Branch candidate	Flexible load
				H2	Flow	Li-ion	LAES		
1	JPRJPRIS3D2_PS1_307_308	Line	81					×	
2	JKRAJKRAG8D_PS1_207_208	Line	9		✓			✓	✓
3	**ACGOS/GOSTIVAR-VRUTO/VRUTOK_1**	Line	48	✓				✓	
4	JBGJBGD1D2_PS1_2_181	Line	7		×			✓	×
5	VIC_PS1_trafo	Transformer	4		×			✓	×
6	VIC_PS2_trafo	Transformer	4		×			✓	×
7	ZEL_RAVNE111_PS1_trafo	Transformer	4		✓			×	✓
8	ZEL_RAVNE111_PS2_trafo	Transformer	4		✓			×	✓
9	ZEL_RAVNE111_PS3_trafo	Transformer	4		✓			✓	✓
10	ZEL_RAVNE111_PS4_trafo	Transformer	4		✓			×	✓
11	JPEJPEJA210_PS1_292_293	Line	8		✓			✓	✓
12	JBGJBGD16D1_PS2_2_85	Line	6		×			✓	×
13	PRIMSKOVO_PS1_trafo	Transformer	4					×	✓
14	PRIMSKOVO_PS2_trafo	Transformer	4					×	✓
15	JRUJRUMA1D2_PS1_2_161	Line	6		✓			✓	✓
16	**ACJLEP/JLEPOS5-JVAL/JVALAC5_1**	Line	18	✓				✓	
17	IL_BISTRICA_PS1_trafo	Transformer	3		×	×	×	✓	×
18	HKR_HKRASI5_PS2_54_56	Line	8		✓			✓	✓
19	**ACJBB/JBBAST21-JRH/JRHBBA21_1**	Line	19					✓	
20	JPRJPRIS3D2_PS1_2_410	Line	7		×			×	✓
21	LOGATEC_PS1_trafo	Transformer	3		×	×	✓	×	✓
22	SL-GRADEC_PS1_trafo	Transformer	3		✓	✓	✓	×	✓
23	HPE_HPEHLI5_PS1_521_522	Line	5		×			×	
24	HPE_HPEHLI5_PS2_2_415	Line	4		×			×	
25	JBGDJBGD47D_PS2_2_60	Line	4		×			✓	×
26	HPE_HPEHLI5_PS1_394_397	Line	4		×			×	
27	PIVKA_PS1_trafo	Transformer	2		×	×	✓	×	✓
28	JPREJPRESED_PS1_23_26	Line	4		×			×	✓
29	JBGDJBGD19D_PS2_59_60	Line	4		×			×	
30	TETTETOVO2_PS2_27_28	Line	5		×	×		×	
31	**ACWPRI/WPRIJ22-HMRACL2(1)99_1**	Line	5	✓			✓	×	
32	HMR_HMRACL5_PS3_trafo	Transformer	3						
33	**ACALA_/ALAC2 5-AMA_/AMAMUR5_1**	Line	10	✓				✓	✓

- Candidates for distribution networks are mostly proposed in the area of Slovenia, southern Serbia, and around Belgrade which coincides with the locations of distribution network congestions.
- As for candidates in the transmission network, they are focused on the most severe congestions in this network (one in Albania, one in Macedonia, two in Serbia, and one between Bosnia and Herzegovina and Croatia).

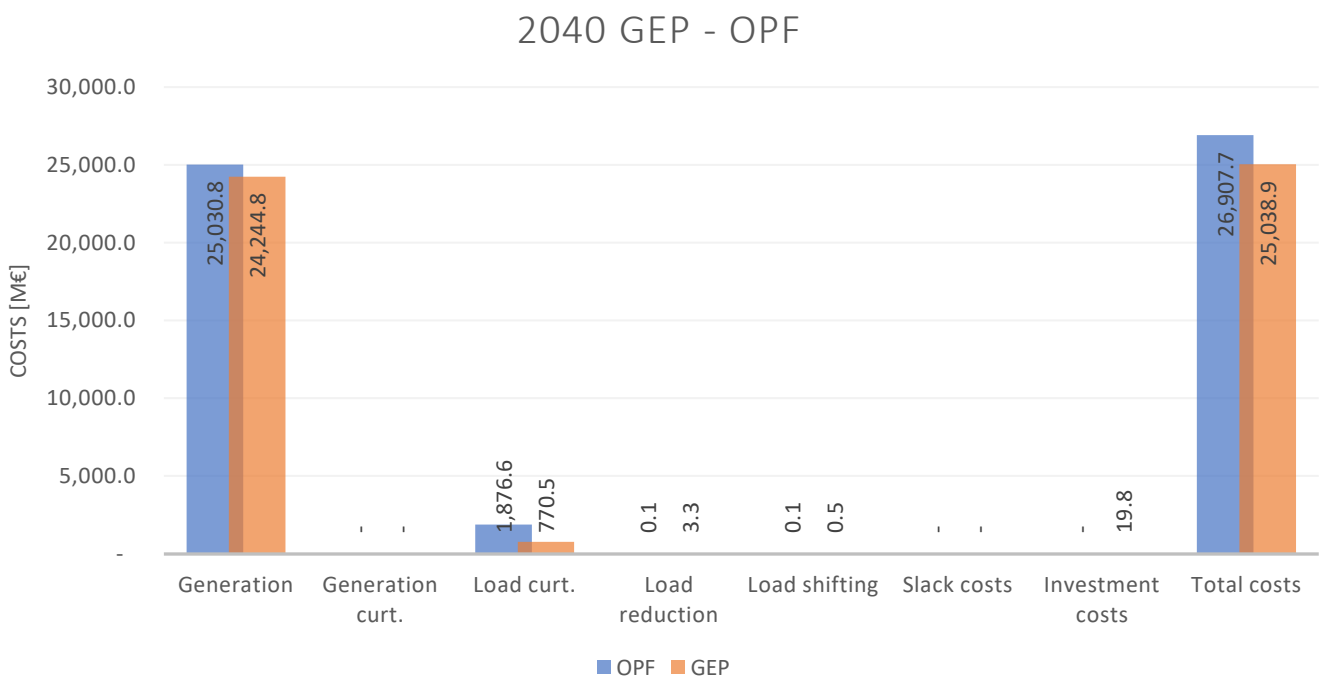
Results of the planning process

FlexPlan

GEP results 2030

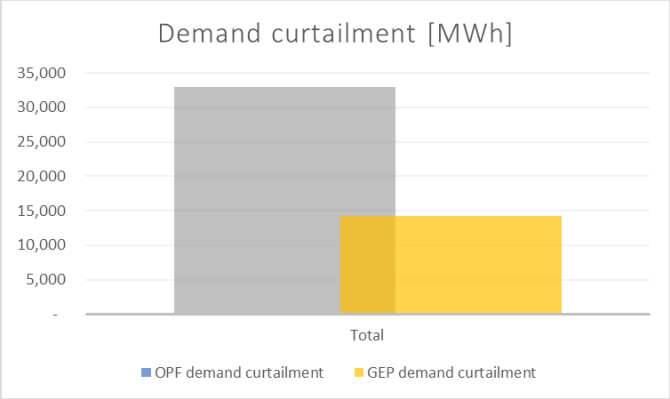
- The GEP process solves a mixed-integer optimization problem aimed at minimizing the total expenditure (CAPEX+OPEX) of the system.

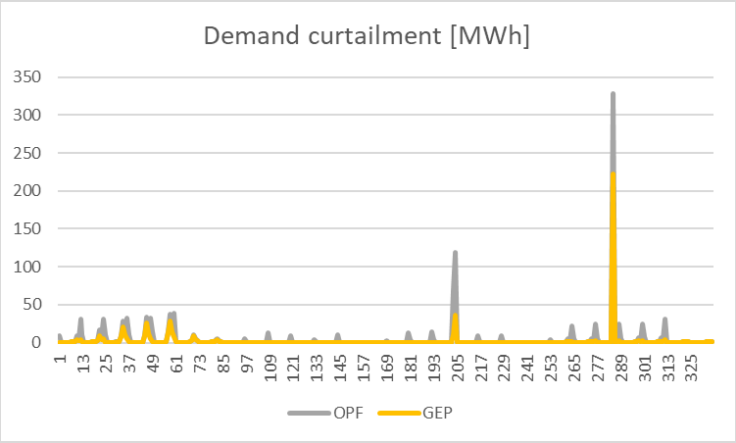
Description of the candidates (Year 2040)					
Type	AC Branch	Transformer	Storage	Flexibility load	Total
Number of candidates	40	0	38	22	100
Investment decisions	6 (Transmission) 11 (Distribution)	0 (Transmission) 0 (Distribution)	4 (H2) 9 (Flow Battery) 1 (Li Battery) 4 (LAES)	16	51
Investment rejected	7 (Transmission) 16 (Distribution)	0 (Transmission) 0 (Distribution)	0 (H2) 15 (Flow Battery) 4 (Li Battery) 1 (LAES)	6	49
Investment costs	13,907,101	0	5,892,247	10,809	19,810,157

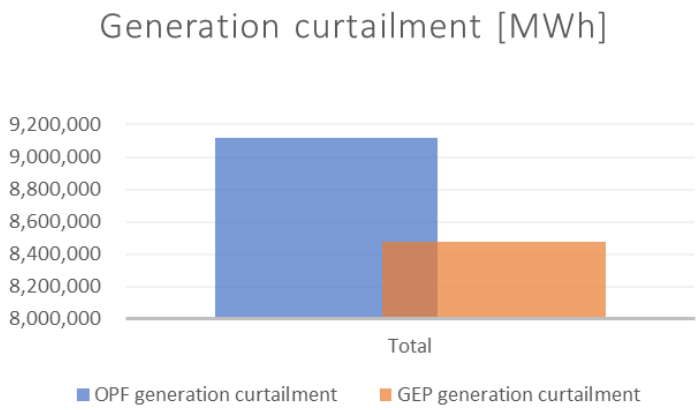


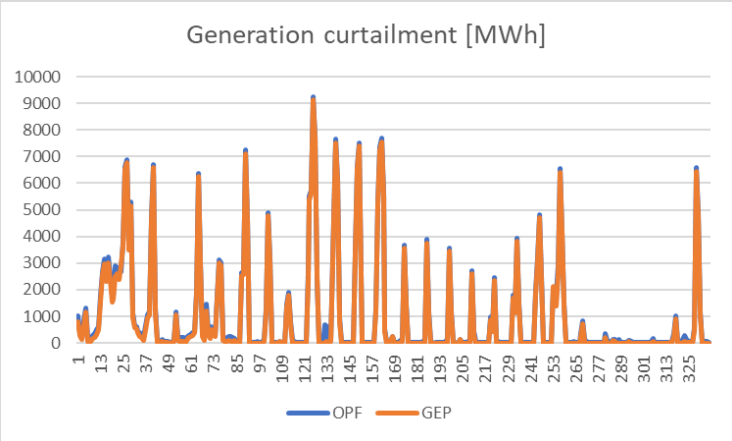
Results of the planning process

GEP results 2030



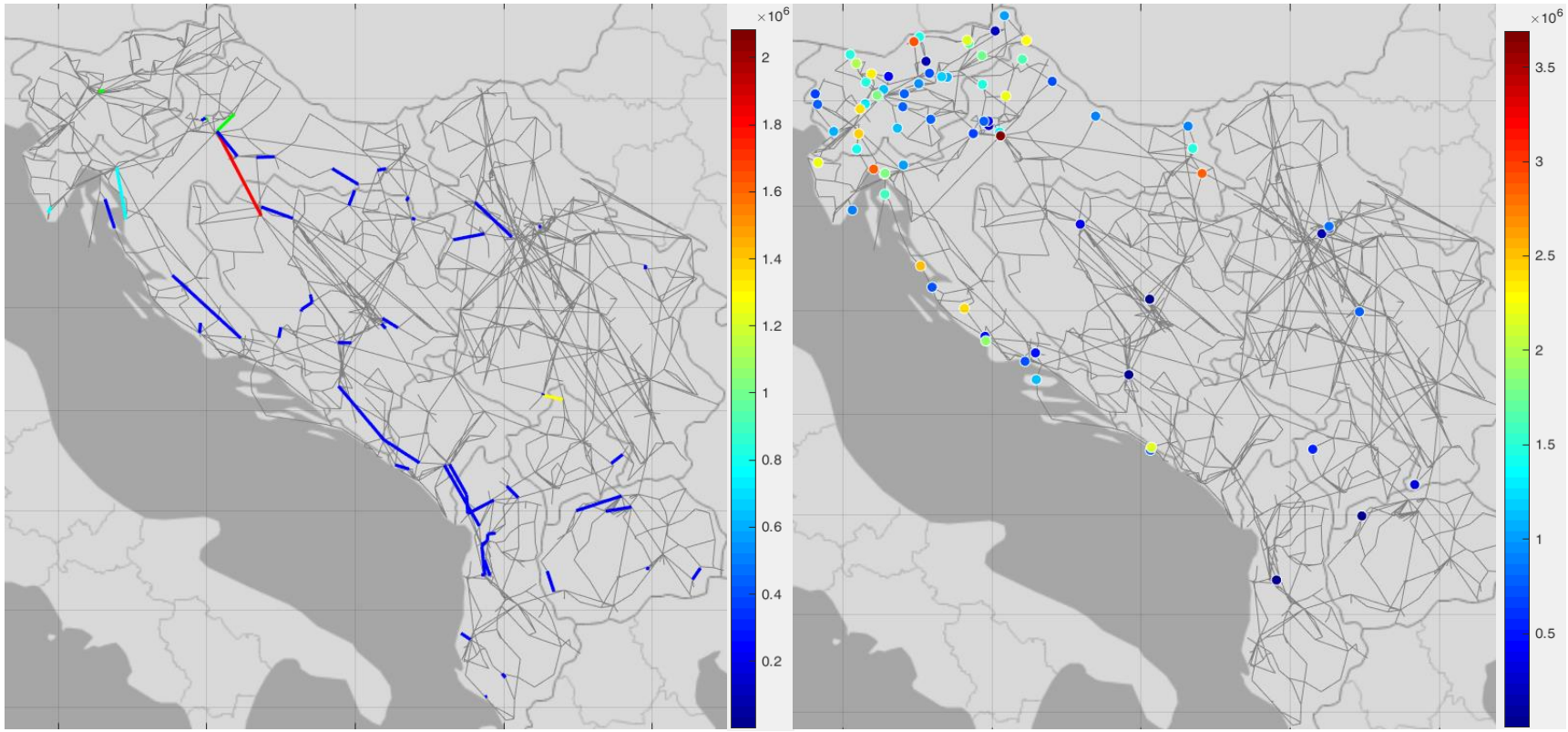






Results of the planning process

Non-expanded OPF 2050

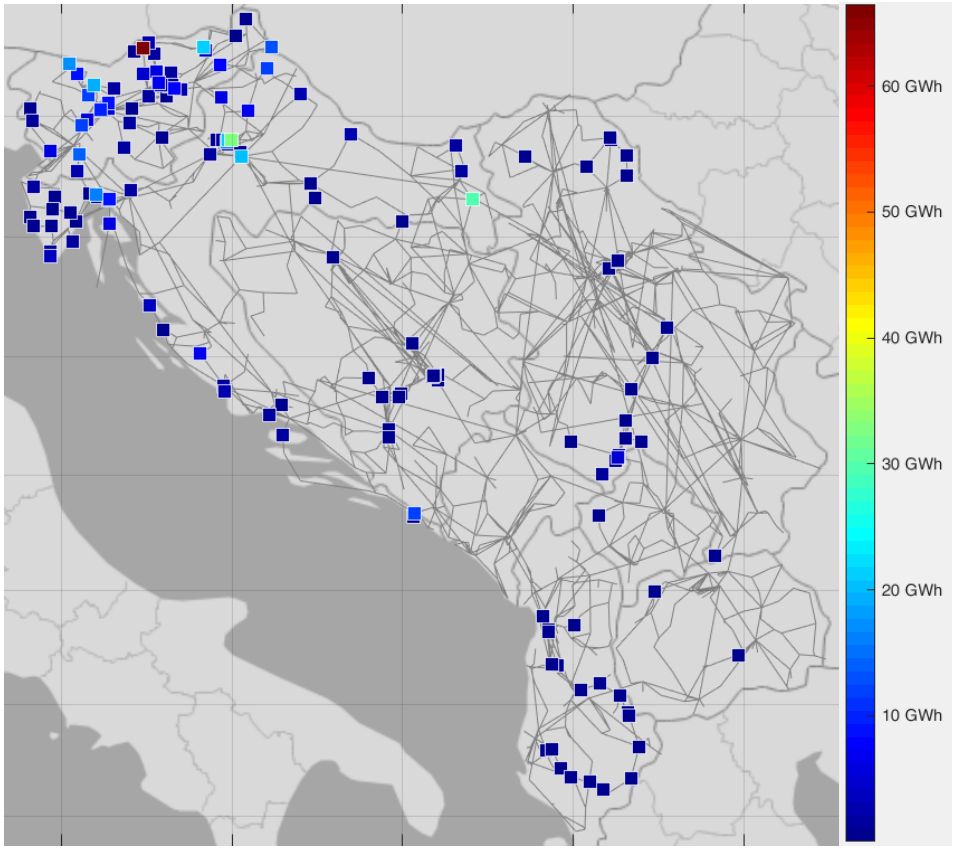


- 212 branches with LM different than 0
- The values of LMs for distribution networks decrease as time progresses, while for the transmission network, they increase and in 2050 the highest congestions reach the same order of magnitude as the highest congestions in distribution networks

Results of the planning process

Non-expanded OPF 2050

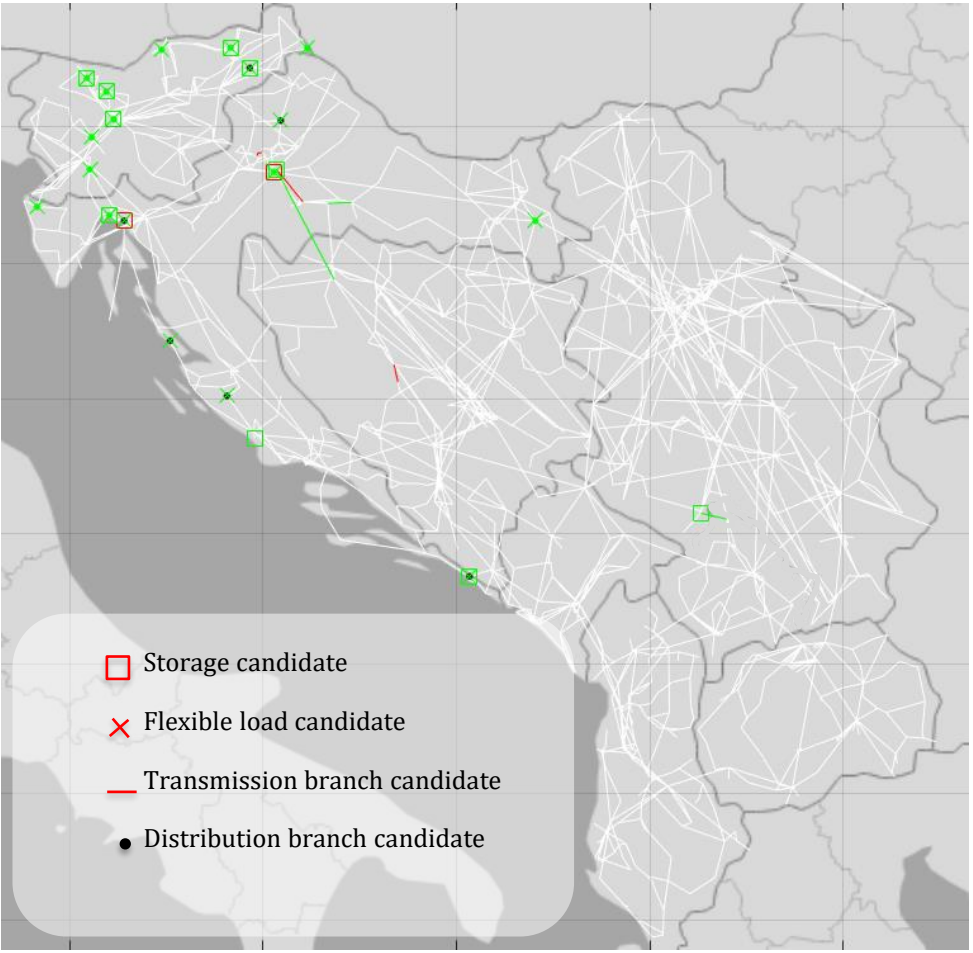
- Demand curtailment still prevails in the distribution networks with a share of about 80% total demand curtailment.
- Generation curtailment dominates in the transmission network with a share of 98% of total generation curtailment.



Results of the planning process

GEP and Pre-processor results 2050

FlexPlan



No.	Branch	Congestion duration	Storage candidate				Branch candidate	Flexible load
			H2	Flow	Li-ion	LAES		
1	HMR_HMRACL5_PS3_trafo	11					✓	✓
2	ZEL_RAVNE111_PS2_trafo	18					✓	✓
3	HPE_HPEHLI5_PS1_521_522	7		✓			×	
4	ZEL_RAVNE111_PS4_trafo	12					✓	
5	HVI_HVINKO5_PS3_trafo	10					✓	✓
6	HVI_HVINKO5_PS1_trafo	10					✓	✓
7	ZEL_RAVNE111_PS1_trafo	11					✓	✓
8	HMR_HMRACL5_PS4_trafo	10					×	✓
9	HVI_HVINKO5_PS4_trafo	10					✓	✓
10	HMR_HMRACL5_PS1_trafo	10					×	✓
11	LOGATEC_PS1_trafo	11					✓	✓
12	PIVKA_PS1_trafo	11					✓	✓
13	HVI_HVINKO5_PS2_trafo	10					✓	✓
14	HMR_HMRACL5_PS2_trafo	10		×			×	✓
15	PRIMSKOVO_PS1_trafo	11		✓			✓	✓
16	HPA_HPAG 5_PS1_trafo	10					×	✓
17	PRIMSKOVO_PS2_trafo	11		✓			✓	✓
18	HBE_HBENKO5_PS1_trafo	10					×	✓
19	LENDAVA_PS1_trafo	10					✓	✓
20	HTE_HTEJER5_PS1_trafo	10					×	✓
21	HPE_HPEHLI5_PS1_662_663	6		✓			✓	✓
22	HBU_HBUJE 5_PS1_2_168	9					✓	✓
23	MELJE_PS2_trafo	10		✓			✓	✓
24	MELJE_PS1_trafo	10		✓			✓	✓
25	**ACWPRI/WPRIJ22-HMRACL2(1)99_1**	14	✓				✓	
26	RADOVLJICA_PS1_trafo	10		✓			✓	✓
27	HKO_HKOMOL5_PS3_trafo	9		✓			×	✓
28	HKO_HKOMOL5_PS4_trafo	9		✓			×	✓
29	HPE_HPEHLI5_PS2_2_415	6		✓			✓	
30	HPE_HPEHLI5_PS1_394_397	5		✓			✓	
31	BRDO_PS1_trafo	10		✓			✓	✓
32	BRDO_PS2_trafo	10		✓			✓	✓
33	HPE_HPEHLI5_PS2_121_129	5		✓			×	✓
34	HKO_HKOMOL5_PS1_trafo	9		✓			×	✓
35	HKO_HKOMOL5_PS2_trafo	9		✓			×	✓
36	**ACJLEP/JLEPOS5-JNPA/JNPAZ25_1**	29	✓				✓	
37	BREG_PS1_trafo	9		✓			×	✓
38	BREG_PS2_trafo	9		✓			×	✓
39	HKR_HKRASI5_PS1_trafo	9		×			×	✓
40	HRA_HRAZIN5_PS1_trafo	9		✓				

- Candidates for distribution networks are mostly proposed in the area of Slovenia and Croatia which coincides with the locations of distribution network congestions (mostly on transformers).
- As for candidates in the transmission network, they are focused on the two most severe congestions in this network.

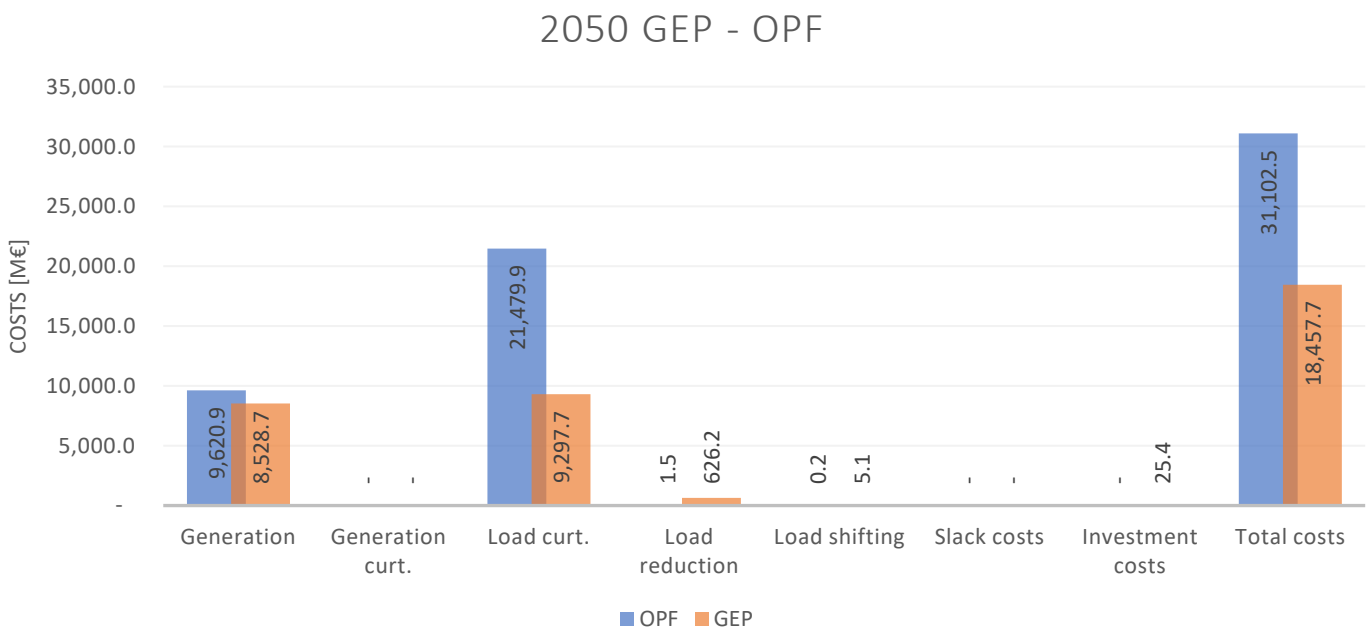
Results of the planning process

FlexPlan

GEP results 2050

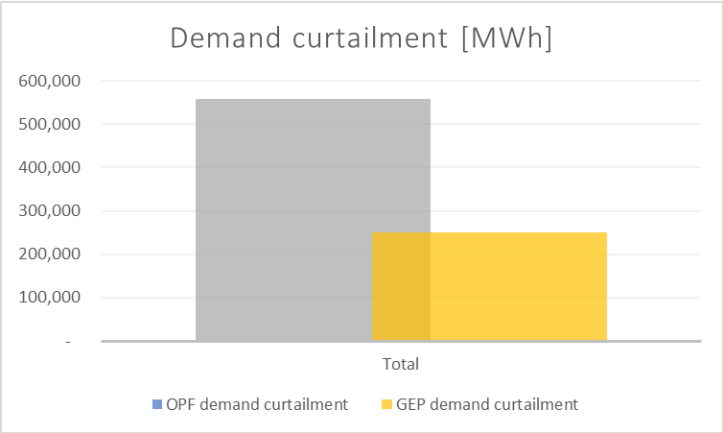
- The GEP process solves a mixed-integer optimization problem aimed at minimizing the total expenditure (CAPEX+OPEX) of the system.

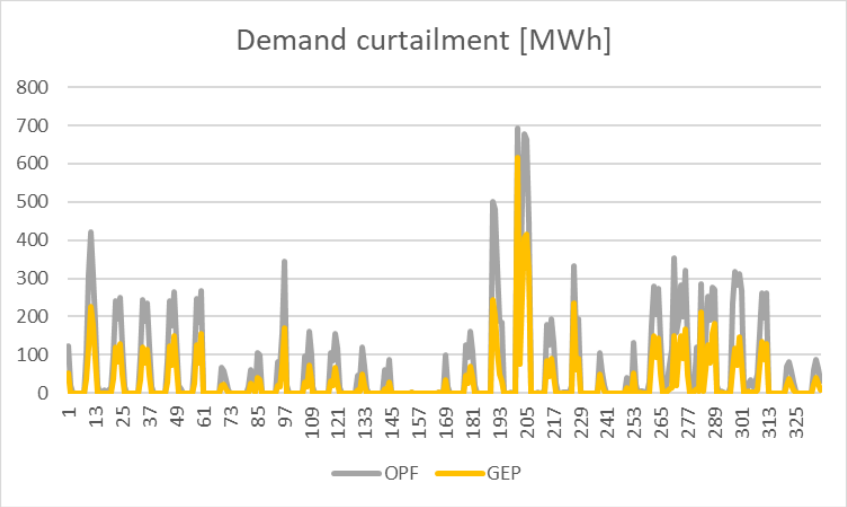
Description of the candidates (Year 2040)					
Type	AC Branch	Transformer	Storage	Flexibility load	Total
Number of candidates	44	0	23	33	100
Investment decisions	3 (Transmission) 22 (Distribution)	0 (Transmission) 0 (Distribution)	2 (H2) 19 (Flow Battery) 0 (Li Battery) 0 (LAES)	33	79
Investment rejected	4 (Transmission) 15 (Distribution)	0 (Transmission) 0 (Distribution)	0 (H2) 2 (Flow Battery) 0 (Li Battery) 0 (LAES)	0	21
Investment costs	19,977,269	0	5,457,204	15,061	25,449,534

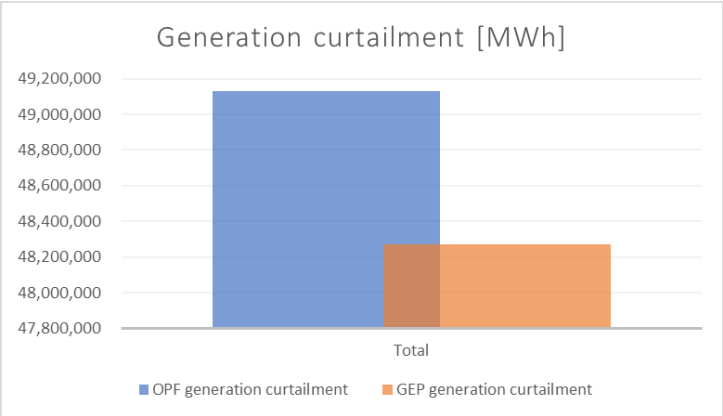


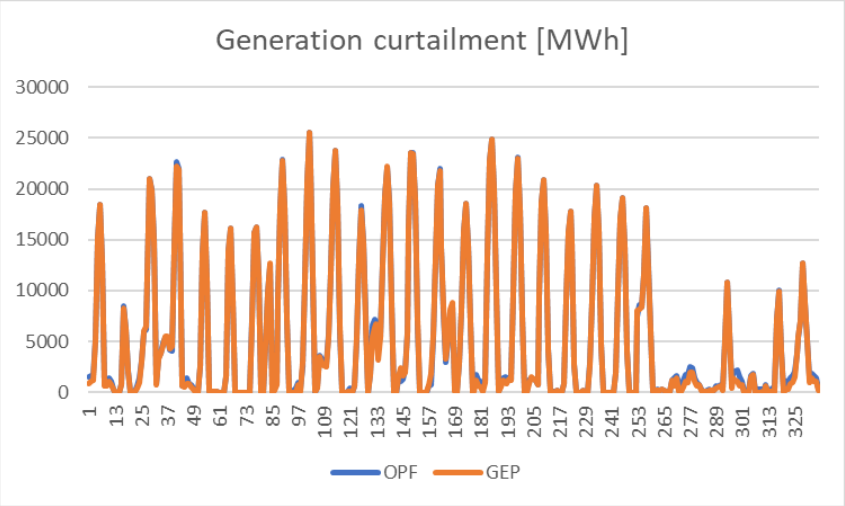
Results of the planning process

GEP results 2030





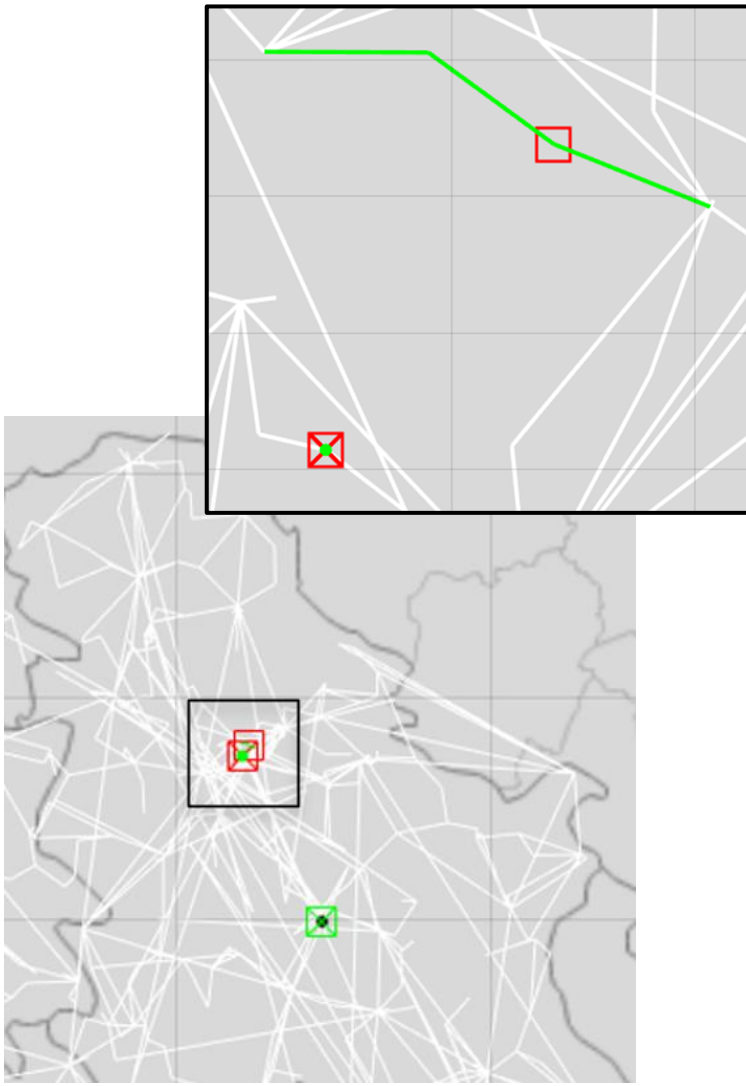




Role of the storage and demand flexibility

For the most severe congestions in transmission network, the Pre-processor proposes:

- ❑ **A set of lines (transformer) reinforcements**
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion) – usually hydrogen storage or LAES due to large energy capacity



<u>CASE A</u>

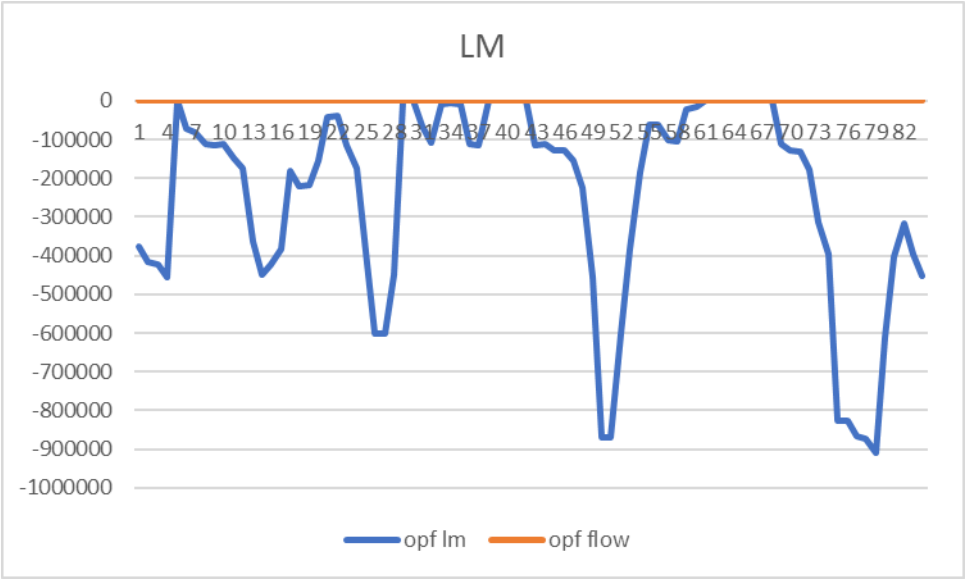
For the most severe congestion (Beograd 17 – Beograd 23) in transmission network for 2030, corridor reinforcement is selected.

- Line reinforcement solves the persistent overloading and significantly decreases the related congestion severity

Role of the storage and demand flexibility

FlexPlan

Candidate	Candidate type	Investment costs [€]	Lifetime [years]
H2_JBG/JBGD2351_JBG/JBGD1752_JBG/JBGD2351	Hydrogen storage	1,766,000	30
AC_JBG/JBGD1752_JBG/JBGD2351	AC branch	2,387,500	50
AC_JBGD/JBGD455_JTTB/JTTBGD5	AC branch	2,137,000	50
AC_JBG/JBGD2351_JBGD/JBGD455	AC branch	1,761,250	50



Role of the storage and demand flexibility

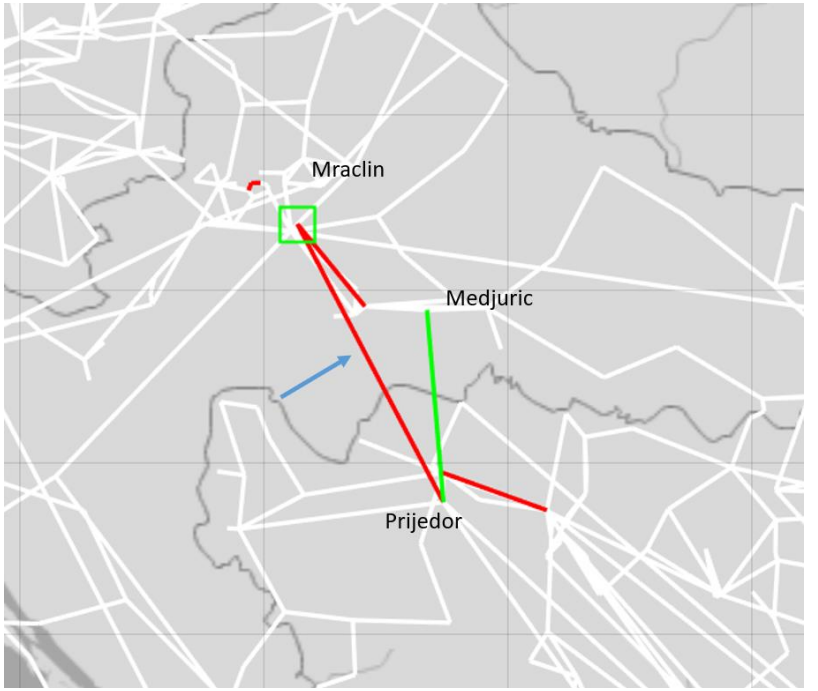
FlexPlan

For the most severe congestions in transmission network, the Pre-processor proposes:

- **A set of lines (transformer) reinforcements**
- **A storage unit** (which size and technology depends on the severity/frequency of the congestion) – usually hydrogen storage or LAES due to large energy capacity

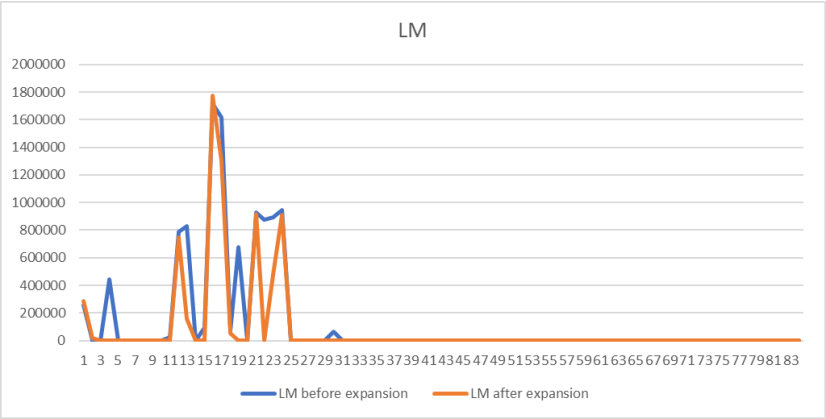
CASE B

For the congestion between Croatia and Bosnia and Herzegovina in transmission network for 2040, hydrogen storage and LAES are selected but also the line that is influenced by the congested branch.

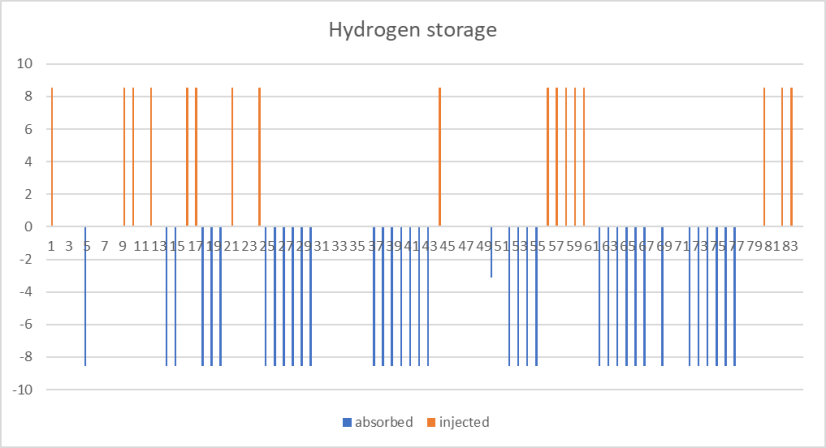


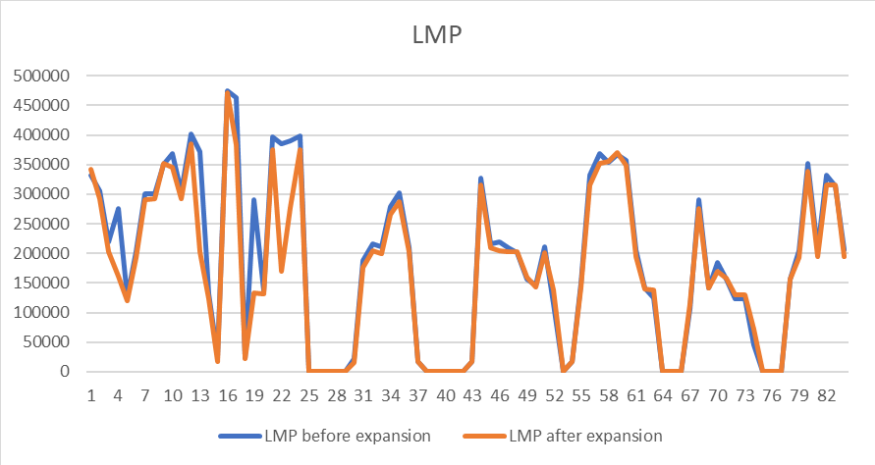
Role of the storage and demand flexibility

FlexPlan



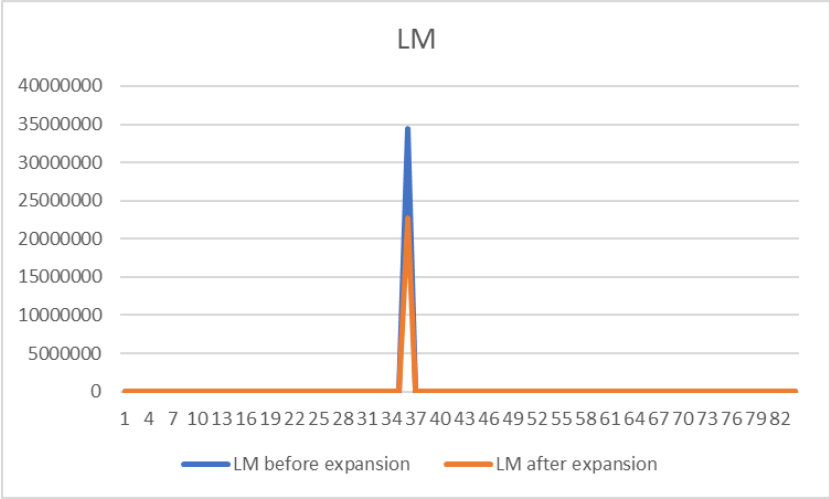
The power rate of storages is not enough to completely remove the congestion in the first week (winter). On the other side, storages perform arbitrage, i.e. they store the energy in hours of lower energy prices (lower LMP) and inject it into the network in hours of higher prices (higher LMP) which makes the overall costs of the system lower.



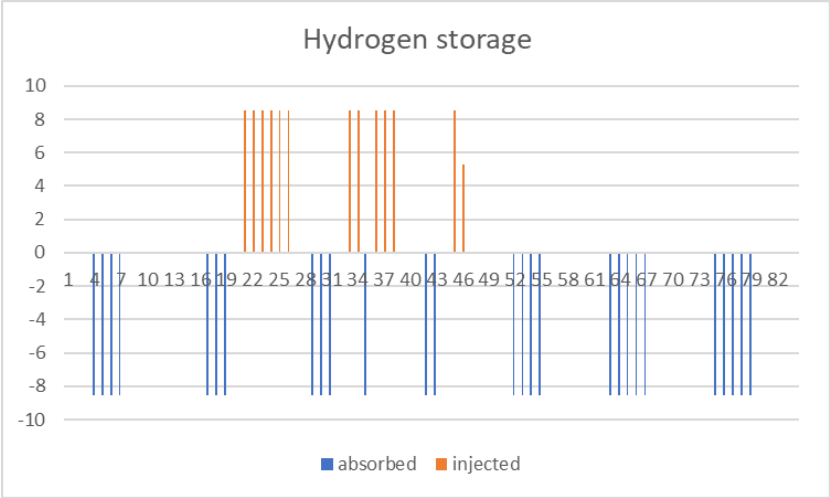


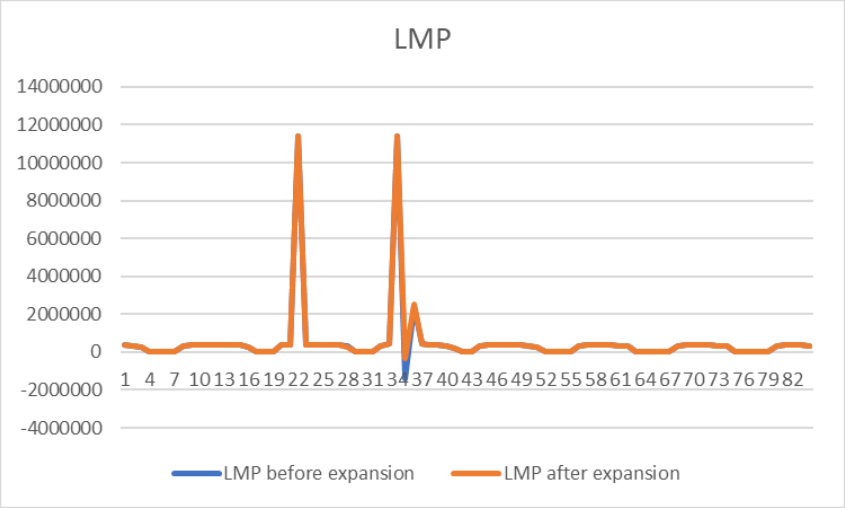
Role of the storage and demand flexibility

FlexPlan



Third week (summer)

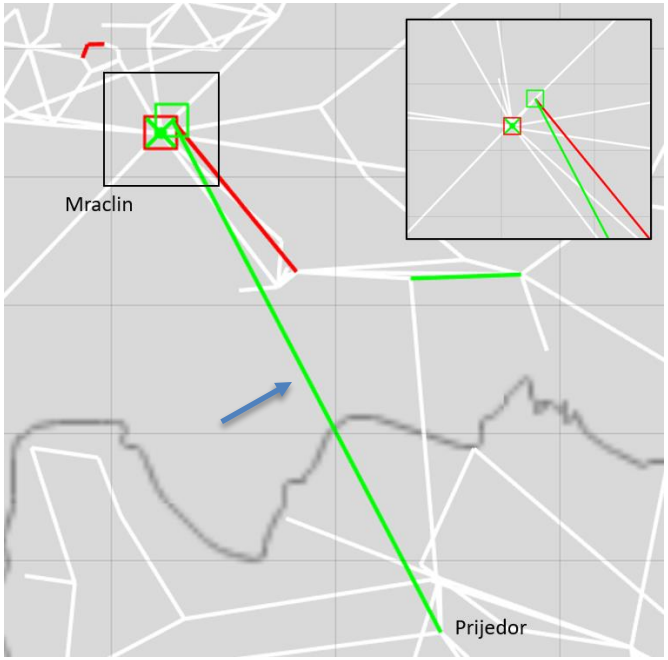




Role of the storage and demand flexibility

For the most severe congestions in transmission network, the Pre-processor proposes:

- **A set of lines (transformer) reinforcements**
- **A storage unit** (which size and technology depends on the severity/frequency of the congestion) – usually hydrogen storage or LAES due to large energy capacity

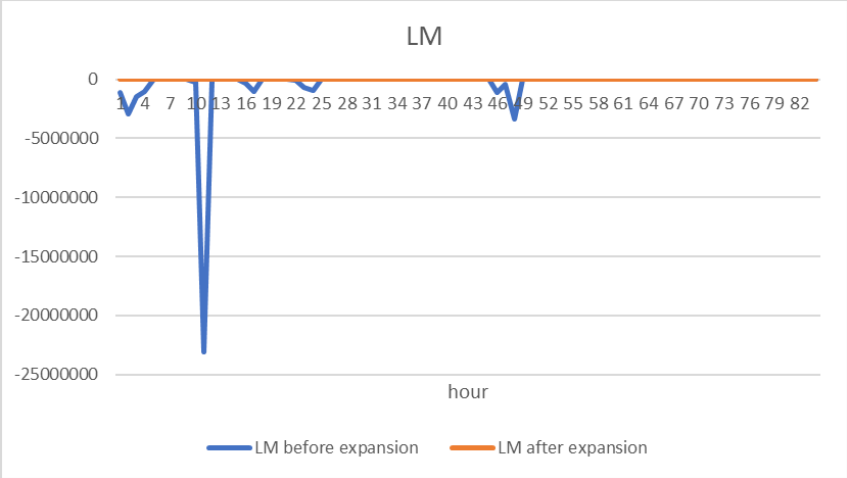


CASE C

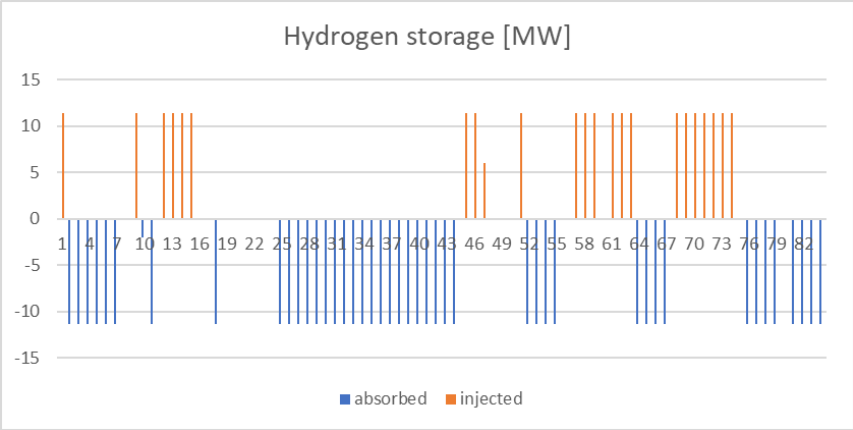
For the congestion between Croatia and Bosnia and Herzegovina in transmission network for 2050, hydrogen storage and reinforcement of congested branch are selected.

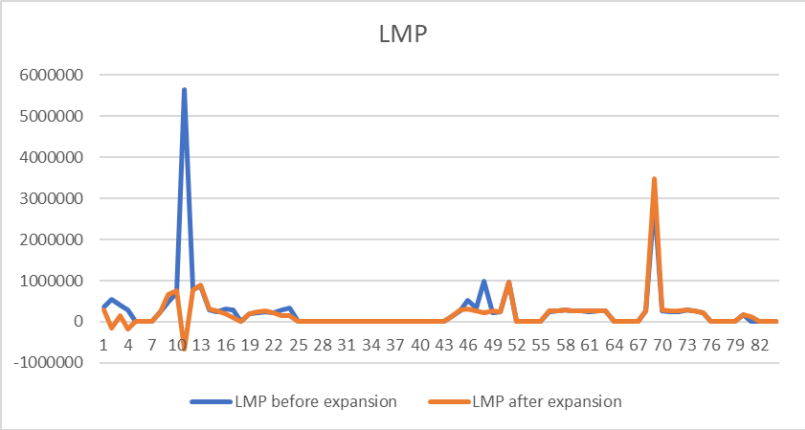
Role of the storage and demand flexibility

FlexPlan



The congestion severity goes to zero, but this time the main credit is attributed to line reinforcement.
In this case storage is selected by the GEP process in order to perform arbitrage functions.

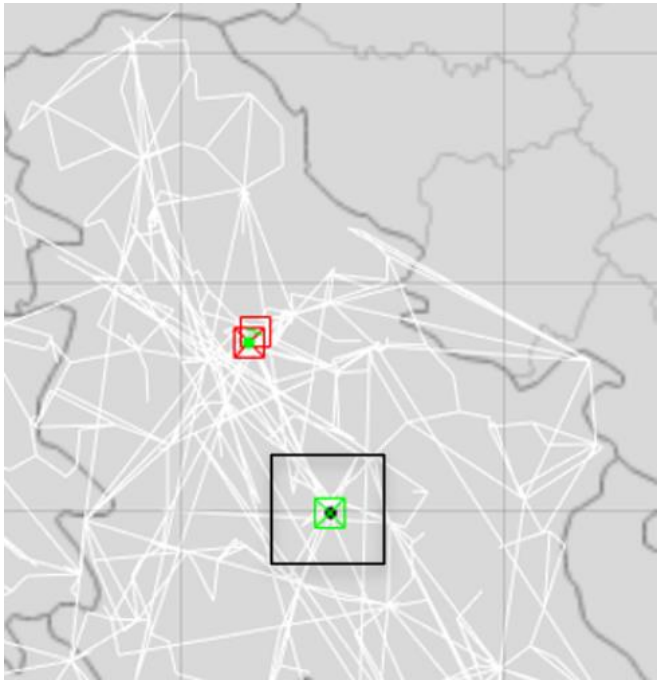




Role of the storage and demand flexibility

For the most severe congestions in distribution network the Pre-processor proposes:

- ❑ **A set of lines (transformer) reinforcements**
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)

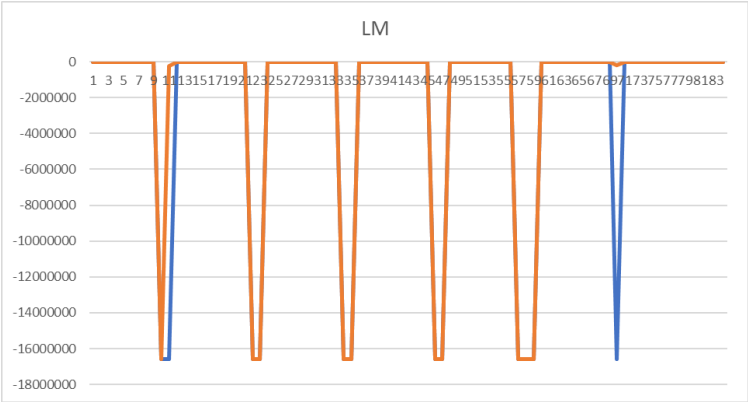


CASE A

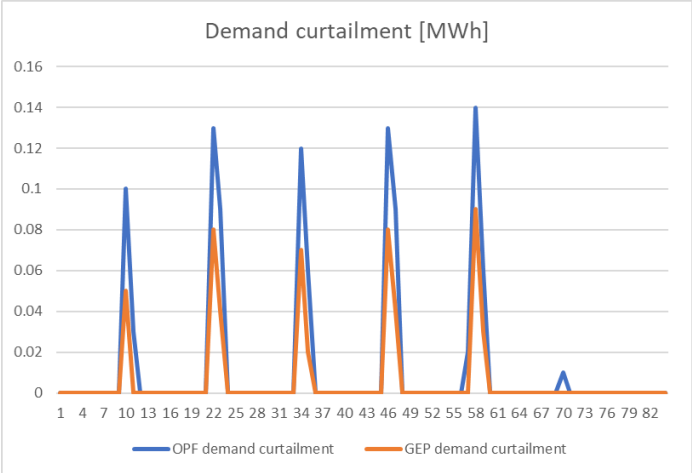
- For the congestion that occurs in distribution network in Kragujevac in 2030, line reinforcement, flow battery and flexible demand are proposed as planning candidates.
- Flow battery is selected.

Role of the storage and demand flexibility

FlexPlan



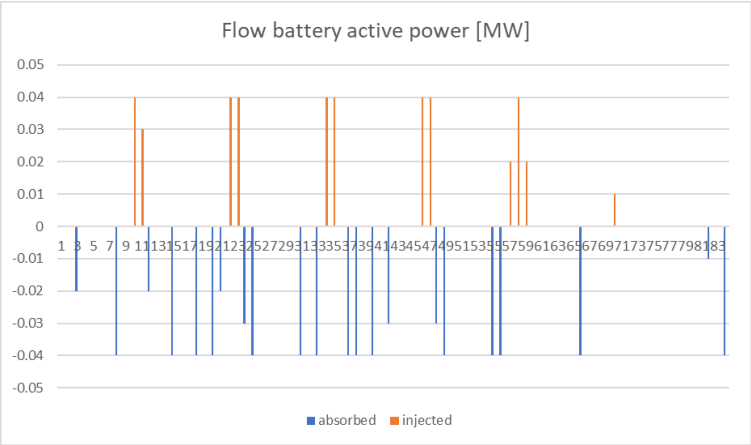
In this case, the selected candidate (storage) did not resolve the congestion for all hours but it supports the reduction of load curtailment which is very costly. The contribution of storage is limited by both the power and energy capacity of the selected device.

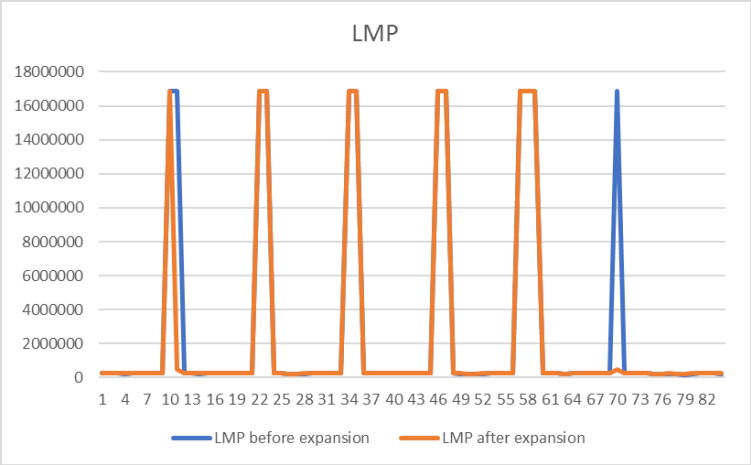


Candidate	Candidate type	Investment costs [€]	Lifetime [years]
JKRAJKRAG8D_PS1_207_208	AC branch	256,995	50
FlowBattery_JKRAJKRAG8D_PS1_208_JKRAJKRAG8D_PS1_207_JKRAJKRAG8D_PS1_208	Hydrogen storage	62,056	30

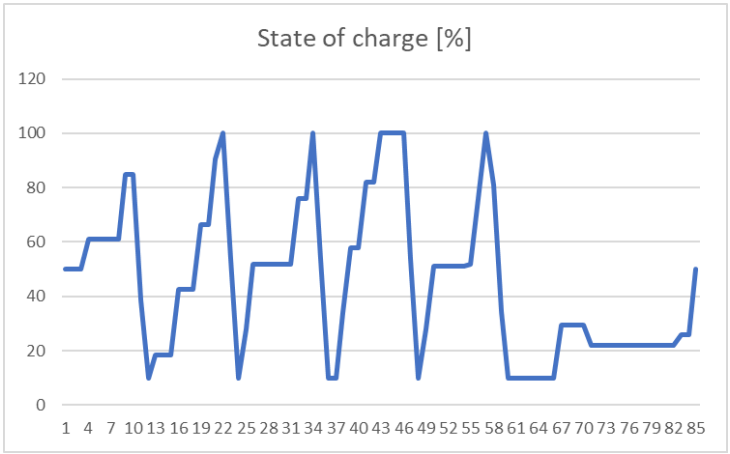
Role of the storage and demand flexibility

FlexPlan





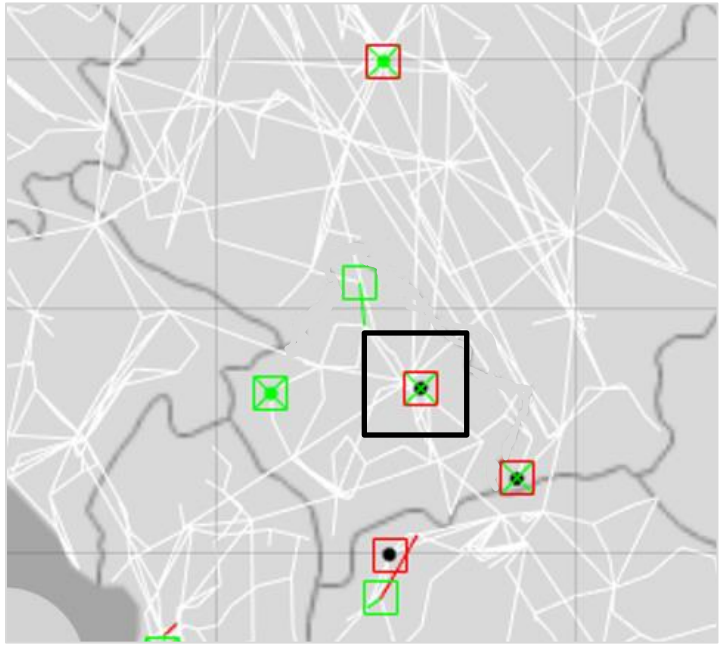
The battery injects energy during congestion hours when the nodal price has the highest value and stores it when these values are very low and thus generates revenue. Having this in mind, as well as that the investment costs of flexible solution is much lower than the reinforcement of existing line, investment in battery is justified.



Role of the storage and demand flexibility

For the most severe congestions in distribution network the Pre-processor proposes:

- ❑ **A set of lines (transformer) reinforcements**
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)

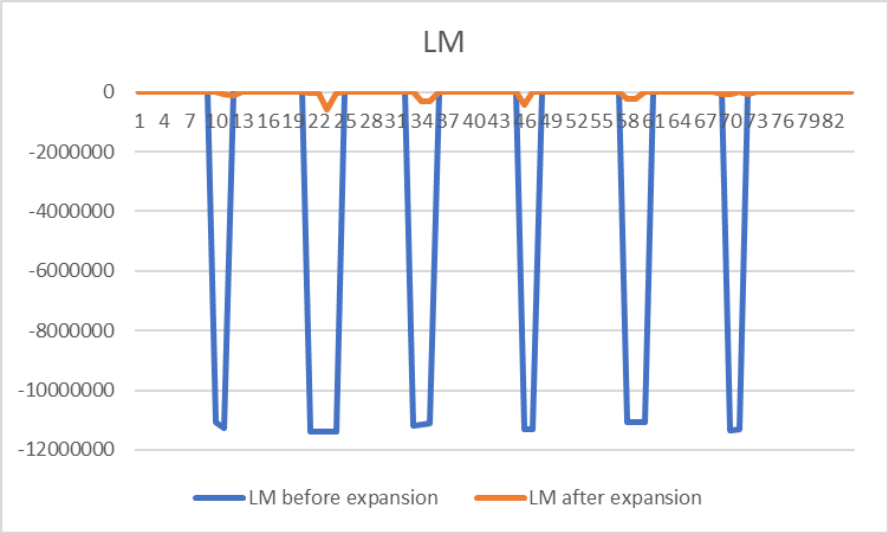


CASE B

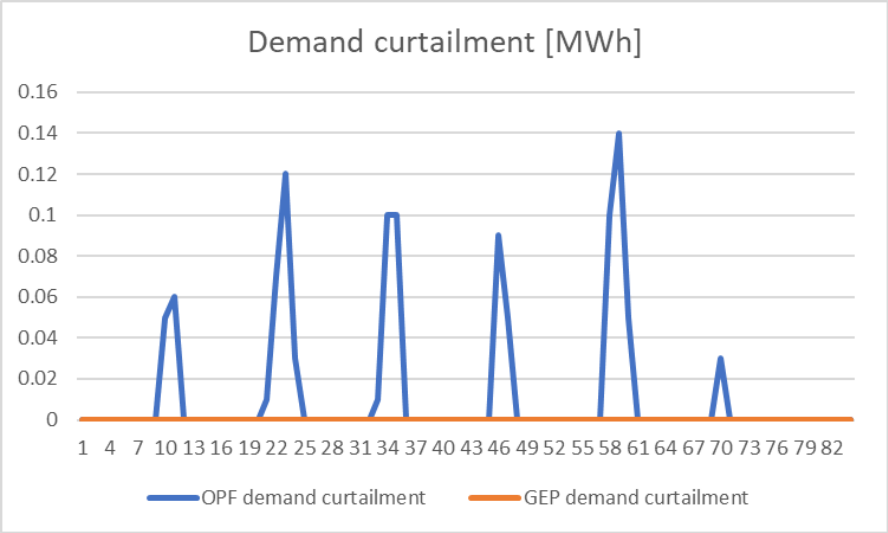
- For the congestion that occurs in distribution network in Serbia in 2040, line reinforcement, flow battery and flexible demand are proposed as planning candidates.
- Only flexible demand is selected.

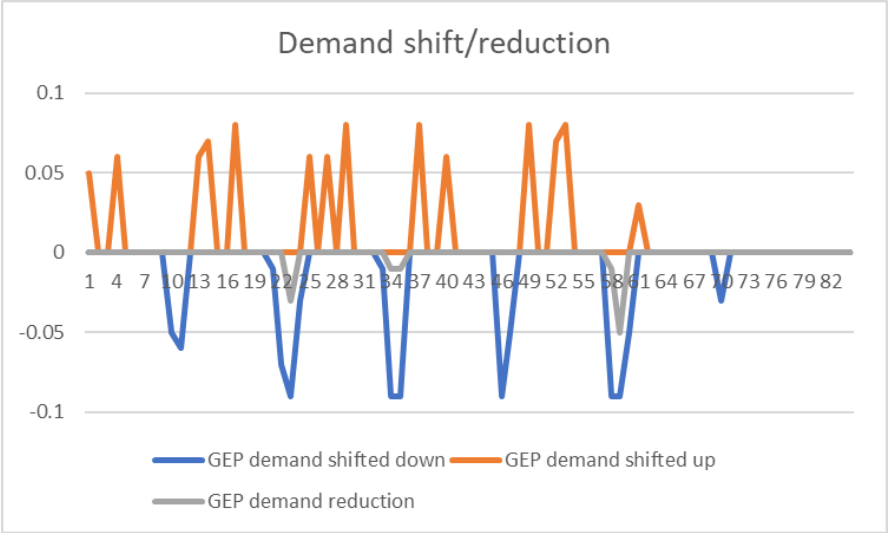
Role of the storage and demand flexibility

FlexPlan



- Congestion occurs due to the insufficient capacity of this branch, which causes load curtailment.
- Demand is first shifted up in the hours when there is no congestion and this is later compensated by shifting down the demand in the hours of congestion. When only shifting down is not enough to relieve the congested branch, the tool also applies a reduction of demand.





Role of the storage and demand flexibility

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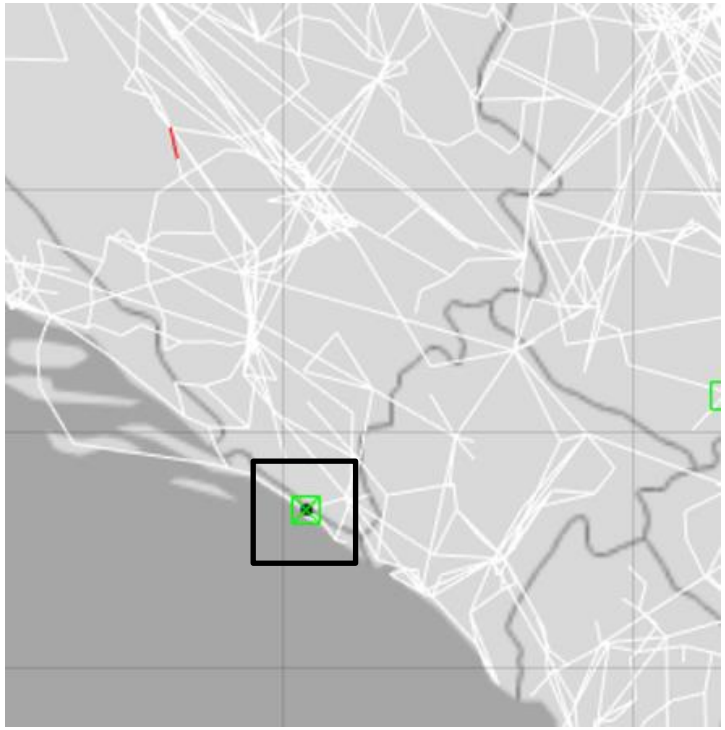
For the most severe congestions in distribution network the Pre-processor proposes:

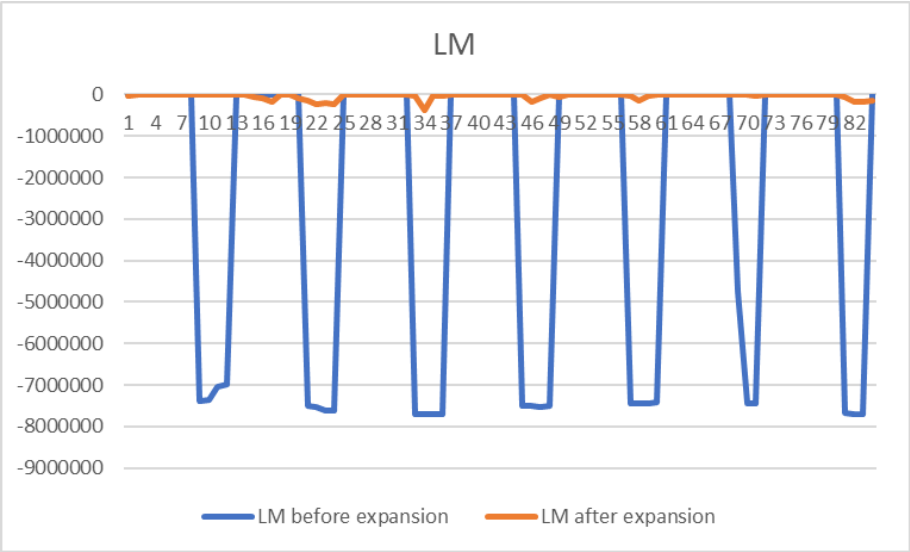
- ❑ **A set of lines (transformer) reinforcements**
- ❑ **A storage unit** (which size and technology depends on the severity/frequency of the congestion)
- ❑ **Flexibilization of existing load** (in case of specific intermittency and severity of the congestion)

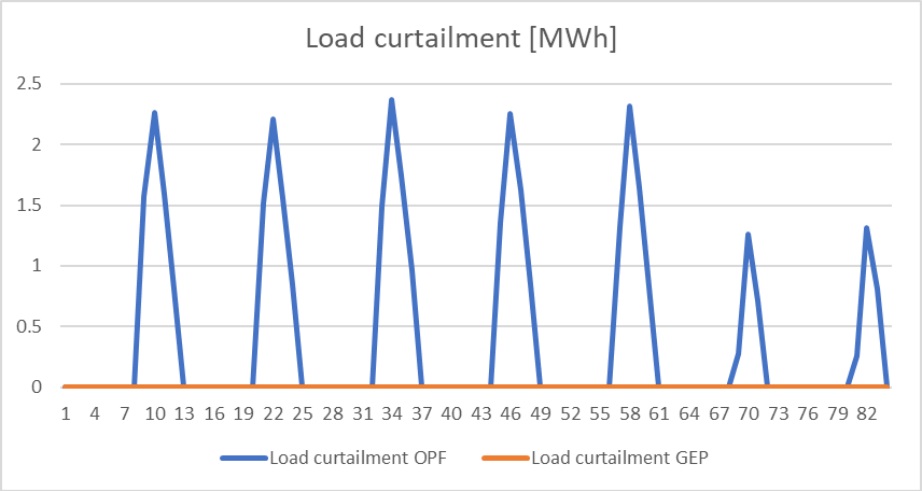


CASE C

- For the congestion that occurs in distribution network in Croatia in 2050, transformer reinforcement, flow battery and flexible demand are proposed as planning candidates.
- Flow battery and flexible demand are selected.

Role of the storage and demand flexibility





- Congestion occurs due to the insufficient capacity of this branch, which causes load curtailment.

Role of the storage and demand flexibility

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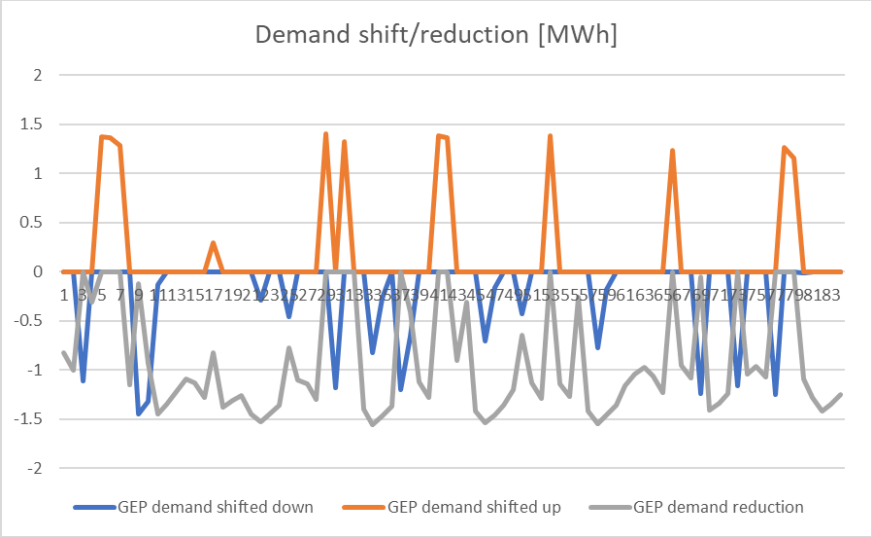
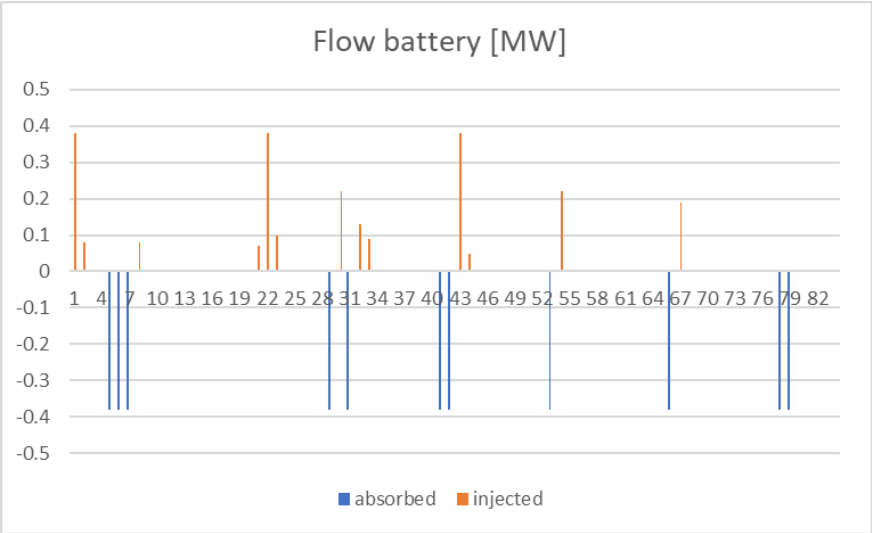
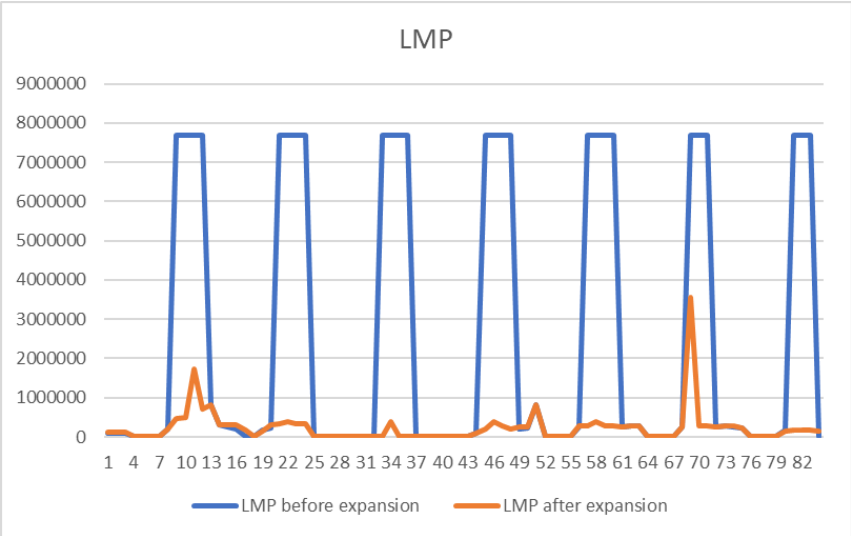


- Demand curtailment is eliminated.
- In this case, the most evident contribution is attributed to the flexible demand i.e demand shifting and reduction.
- The battery mainly injects power during hours when there is no congestion or demand curtailment thus it was chosen by the GEP to perform the arbitrage functions. The revenue of the arbitrage is sufficient to justify storage investment.





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Questions?

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Thank you…

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