Assessing Power System Flexibility with IRENA FlexTool

Hands-on 4

Please use the following citation for:

- **This exercise**

Plazas-Niño, F. (2025, April). Hands-on 4: Assessing power system flexibility with FlexTool (Version 1.0.). Climate Compatible Growth. DOI: 10.5281/zenodo.17070502

- **FlexTool software**

IRENA. (2024). FlexTool (Version v2.0.0). https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Nov/IRENA_FlexTool_v_2_0.zip

- **FlexTool Forum**

Please sign up to the help forum here. If you are stuck, please ask questions here. If you get ahead, please answer questions in the same forum. Please state that you are using the version 2.0.

Learning outcomes

By the end of this exercise you will be able to:

1) Identify the flexibility issues in a case study.

2) Analyze the impact of storage options on addressing flexibility issues.

3) Analyze the impact of transmission on addressing flexibility issues.

Activity 1 – Fossil-fuel-based system

In this series of exercises, we will work on a case study with different flexibility options on both the supply and demand sides. For this first hands-on practice, we will focus on the supply side, as studied in Lecture 5.

Note: The numbers used in this case study do not represent real-world values.

Please follow the steps below:

1. Download the input file named *"Case-study1.xlsm"* from the link provided: https://zenodo.org/records/17070502
2. Save *"Case-study1.xlsm"* in the root folder *"\FlexTool-v2.0\InputData"*.
3. Open the FlexTool main interface (the *"flexTool.xlsm"* Excel file) and add *"Case-study1.xlsm"* to the active input files.
4. Add the *Base* scenario to the active scenarios.
5. Run the model and wait for the result file to open.

In this first case, you will notice that all flexibility options are disabled, either because the installed capacity is zero (e.g., hydropower generators) or because there is no demand (e.g., heat). Additionally, this is a fossil-fuel-based system with some contributions from biomass and geothermal energy. If you explore the input data file further, you will find that the installed capacity of the system is as follows:

- **Node A:** 2,500 MW of ST coal and 1,000 MW of ST gas
- **Node B:** 800 MW of ST biomass and 750 MW of geothermal
- **Node C:** 1,500 MW of CC oil

In this context, the system doesn't present flexibility issues as shown in the summary_D sheet.

	A	B
1	Update sheets window	Case-study1
2		Base
22	General results	elec
23	VRE share (% of annual demand)	0
24	Loss of load (% of annual demand)	0
25	-> ramp up constrained (% of annual demand)	0
26	Excess load (% of annual demand)	0
27	Insufficient reserves (% of reserve demand)	0
28	Insufficient inertia (% of inertia demand)	0
29	Curtailment (% of VRE gen.)	
30	-> ramp down constrained (% of VRE gen.)	
31	Peak load (MW)	5510.97
32	Peak net load (MW)	5510.97

Activity 2 – Renewables-based system

Now, let's consider a different expansion plan where variable renewable energy (VRE) is the key element. We will repeat the process as before, but this time using *"Case-study2.xlsm"* from the link provided: https://zenodo.org/records/17070502 . In this new case, the penetration of wind and solar PV in the different nodes is higher. The installed capacities are as follows:

- **Node A:** 750 MW of ST coal, 400 MW of ST gas, 2,500 MW of wind, and 1,000 MW of solar PV
- **Node B:** 450 MW of ST biomass, 500 MW of geothermal, and 1,500 MW of solar PV
- **Node C:** 500 MW of CC oil, 1,500 MW of wind, and 1,200 MW of solar PV

With this high penetration of VRE sources, the number of flexibility issues is considerable. Let's begin by checking the *Summary_D* sheet and identifying the key problems. The values are presented below for reference.

	A	C
22	General results	elec
23	VRE share (% of annual demand)	43.72
24	Loss of load (% of annual demand)	36.64
25	-> ramp up constrained (% of annual demand)	0.3841
26	Excess load (% of annual demand)	0
27	Insufficient reserves (% of reserve demand)	0
28	Insufficient inertia (% of inertia demand)	0
29	Curtailment (% of VRE gen.)	1.246
30	-> ramp down constrained (% of VRE gen.)	0.003834
31	Peak load (MW)	5510.97
32	Peak net load (MW)	4677.3

Please also review the remaining results and check for load shedding, VRE curtailment, ramping capabilities, reserves, etc., across the different nodes.

Questions:

- Which node has the highest load shedding for power?
- Which node has the highest VRE curtailment?
- Which node has the highest outgoing power transfer?
- Are there issues with ramping capabilities (upward or downward) in the different nodes?

Conclusion:
After analyzing the points above, we can conclude that the system is experiencing a significant loss of load, particularly at night and during weekends. This load shedding occurs across all nodes. At the beginning of the week, when demand is lower, curtailment problems appear during the daytime in all nodes. Transmission capacity is underutilized across the system. This issue is also evident in the ramping plots, which show several challenges in meeting upward and downward ramping requirements.

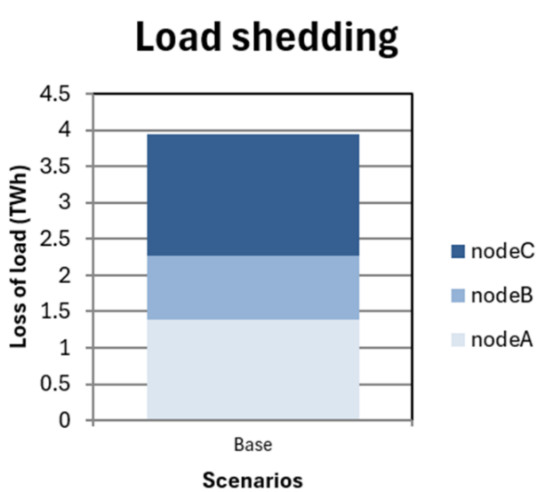
In the following activities, we will introduce different flexibility options on the supply side and investigate how their implementation affects the results.

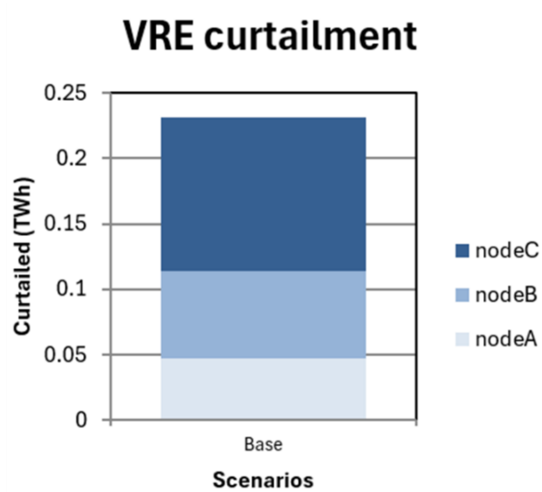
Activity 3 – Balancing through time

In principle, this does not appear to be a problem of capacity inadequacy, since fossil fuel units are not being used to their maximum potential and the VRE share does not exceed 45%.

69	Unit type	Utilization (%)
70	ST_coal	51.07
71	Engine_gas	91.95
72	CC_oil	39.65
73	ST_bio	79.22
74	Geothermal	94.35
75	Hydro_RES	0
76	Hydro_ROR	0
77	wind	28.78
78	PV	16.67

Since we are experiencing loss of load and curtailment across all nodes, the issue is likely related to temporal balancing.





To address these issues, we will activate the option to invest in storage technologies: batteries in Node A and pumped hydro in Node C.

Instructions:

1. Activate the *max invest* values for both technologies as illustrated below.
2. Close the input file.

3. Add Invest to the active scenarios (while keeping the Base scenario active for comparison).
4. Run the model and wait for the result file to be created.

Add empty row

Choose one input option (none, fuel, cf profile, inflow **or** input grid+node)

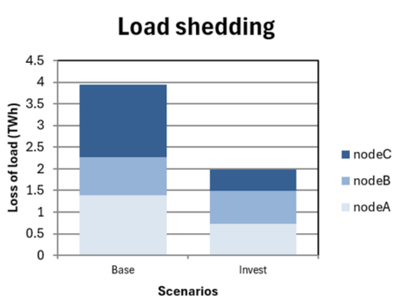
Output #1

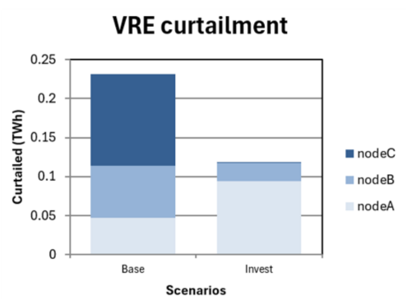
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	unitGroup	unit type	fuel	cf profile	inflow	input grid	input node	output grid	output node	capacity (MW)	invested capacity (MW)	max invest (MW)	storage (MWh)	invested storage (MWh)	max invest (MWh)
7	Battery	battery						elec	nodeA	0		500	0		1000
26	PumpHydro	pumpHydro						elec	nodeC	0		500	0		25000

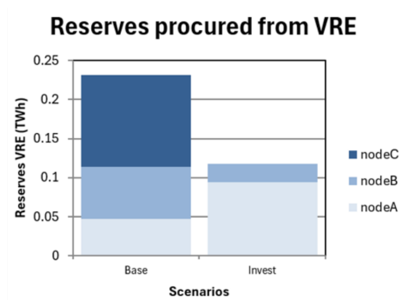
Question:

- Did investment in storage technologies reduce the loss of load? What about VRE curtailment?
- Does the share of VRE increase in the Invest scenario with respect to the Base scenario?

Check the results for Invest scenario in “summary_D” sheet and then go to the "node_plot" sheet and compare the load shedding and VRE curtailment for *Base* and *Invest* scenarios.







1. Investment in storage technologies has reduced total system cost.
2. Investment in storage technologies has reduced the loss of load in all nodes.
3. Increased investment in storage technologies has reduced the VRE curtailment in nodes C and B, although there is more curtailment in node A. This can be due to the following:
    - Lack of sufficient flexibility sources (storage, demand response, etc.) in node A.
    - Lack of sufficient transmission between the nodes.
    - Excess investment in the absence of demand growth.

Try it: Check the system configuration and technology mix in "units_elec" and "transfer_elc"

Activity 4 – Balancing through space

In the previous case, we used storage as a way to provide greater flexibility to the system before considering upgrades to the transmission line. This is a typical example of **transmission deferral**. Transmission deferral occurs when investments in new transmission lines or upgrades are postponed because other flexibility options in the power system make it possible to deliver reliable electricity without immediately expanding grid capacity.

In this final case, we will analyze the impact of an **optimized transmission network** by enabling investment in transmission lines, including the previously non-existent **Node A–Node C** linkage.

Instructions:

1. Return to the **"Case-study2.xlsm"** file.
2. In the *nodeNode* sheet, set the *max invest* values to **1,000 MW** for all lines, as shown in the figure.
3. Run the model in both **Base** and **Invest** modes to analyze the results.

1	grid	node1	node2	cap.rightward (MW)	cap.leftward (MW)	invested capacity (MW)	max invest (MW)	loss	inv.cost/kW	lifetime	interest	annuity	HVDC	color in results
2	elec	nodeA	nodeB	150	150		1000	0.01	100	50	0.08	0.082	0	
3	elec	nodeB	nodeC	100	100		1000	0.01	100	50	0.08	0.082	0	
4	elec	nodeA	nodeC	0	0		1000	0.01	100	50	0.08	0.082	0	

Note: This new case has re-optimized the storage options, so storage requires a new analysis in light of the transmission options.

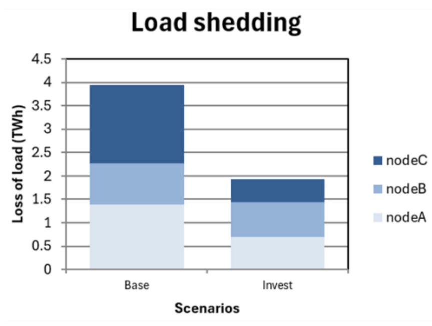
Questions:

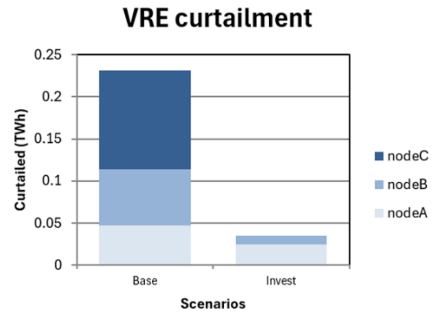
- How does storage deployment change compared to the previous case?
- What are the optimal investments in transmission?
- What reductions in load shedding and curtailment are observed across nodes?

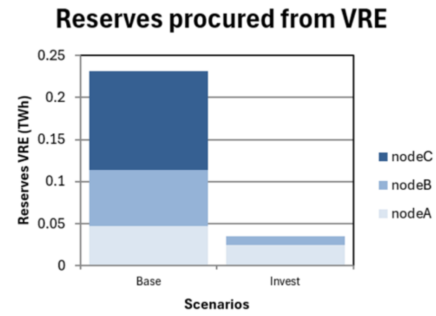
By reviewing the transfer results in the summary_D sheet, we can see that investments were made in all three transmission lines. However, their utilization factors remain low.

145	Transfer	Utilization (%)	Utilization (%)
146	nodeA - nodeB	11.1	21.8
147	nodeB - nodeA	27.91	18.94
148	nodeA - nodeC	0	35.84
149	nodeC - nodeA	0	3.374
150	nodeB - nodeC	24.34	37.29
151	nodeC - nodeB	14.04	1.212
152			
153	Transfer	Capacity (MW)	Capacity (MW)
154	nodeA - nodeB	150	222.704
155	nodeB - nodeA	150	222.704
156	nodeA - nodeC	0	196.645
157	nodeC - nodeA	0	196.645
158	nodeB - nodeC	100	375.471
159	nodeC - nodeB	100	375.471

In terms of flexibility issues, the reduction in loss of load is minor, while curtailment decreases from 0.75% to 0.22% of VRE generation. This also has a positive effect by reducing the reserves procured from renewables.



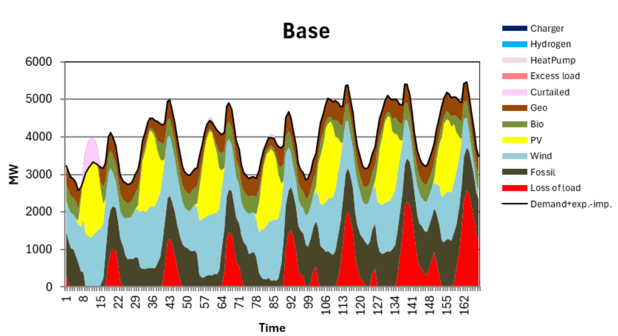


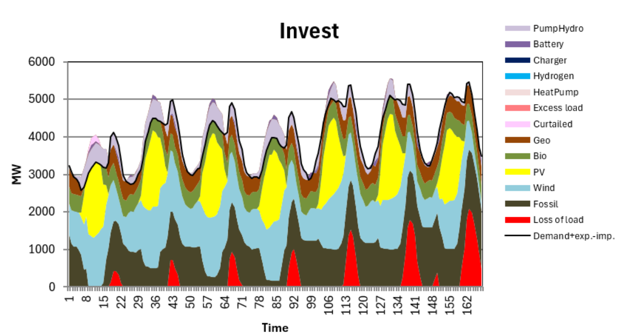


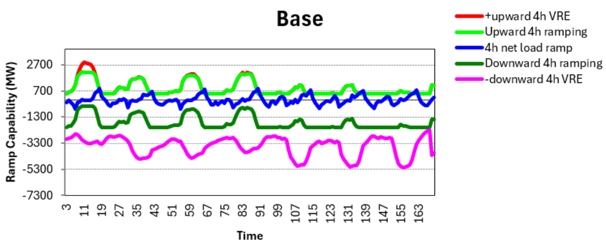
Try it :

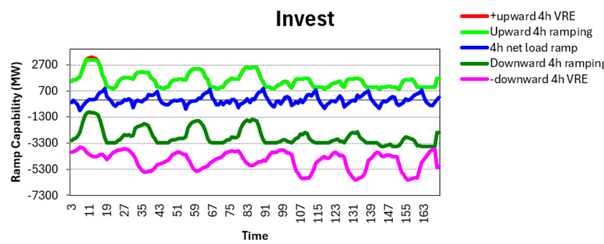
There are several additional alternatives you can explore to address these flexibility issues:

1. By reviewing the *units_invest_plot* sheet, you will see that the shadow values of batteries and pumped hydro are negative. This indicates that increasing investment in these technologies in nodes A and C could be beneficial.
2. Add a storage technology in node B and set a maximum investment level similar to the examples in nodes A and C, in order to verify its additional contribution in this node.
3. From the dispatch profiles shown below, we can observe upward ramping issues that result in loss of load. This is also noticeable in the ramping plots. To mitigate this, you can add generation capacity from more flexible thermal power plants, such as Engine_gas or Gas_CT.






Base
+upward 4h VRE
Upward 4h ramping
4h net load ramp
Downward 4h ramping
-downward 4h VRE
Ramp Capability (MW)
Time


Invest
+upward 4h VRE
Upward 4h ramping
4h net load ramp
Downward 4h ramping
-downward 4h VRE
Ramp Capability (MW)
Time