Assessing Power System Flexibility with IRENA FlexTool

Hands-on 5

Please use the following citation for:

- **This exercise**

Plazas-Niño, F. Hoseinpoori P., Kell A., & Hawkes A. (2025, April). Hands-on 5: Assessing power system flexibility with IRENA FlexTool (Version 1.0.). Climate Compatible Growth. DOI: 10.5281/zenodo.17070546

- **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

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Learning outcomes

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

1) Analyze the impact of demand response on addressing flexibility issues.

2) Analyze the impact of power to heat on addressing flexibility issues.

3) Analyze the impact of power to hydrogen on addressing flexibility issues.

4) Analyze the impact of power electric vehicles on addressing flexibility issues.

Activity 1 – System with High Renewable Share

We will now analyze a system with a high penetration of renewables and additional grids: heat, hydrogen, and electric vehicles. In this exercise, we will explore possible ways to address flexibility challenges using demand-side strategies.

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-study3.xlsm”** from the link provided: https://zenodo.org/records/17070546
2. Save **“Case-study3.xlsm”** in the root folder: InputData\FlexTool-v2.0.
3. Open the FlexTool main interface (the **“flexTool.xlsm”** Excel file) and add **“Case-study3.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 the “summary_D” sheet in the result file, try to identify the flexibility issues by checking the values represented bellow for the different grids (electricity grid is shown as example):

	A	B
1	Update sheets window	Case-study3
2		Base
22	General results	elec
23	VRE share (% of annual demand)	69.25
24	Loss of load (% of annual demand)	5.616
25	-> ramp up constrained (% of annual demand)	0.2876
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.)	5.333
30	-> ramp down constrained (% of VRE gen.)	0.04758
31	Peak load (MW)	5398.49
32	Peak net load (MW)	4124.26

In the “node_plot” sheet, check for the load shedding, VRE curtailment, Reserve procured from VRE etc., in different nodes.

Question:

- Which node has the highest load shedding for power?
- Which node has the highest VRE curtailment?
- Which node has the highest outgoing power transfer?
- Which flexibility issue can you observe in the heat grid? What do you think the reason is?
- Are there additional flexibility issues with hydrogen and electric vehicles?

Try it:

- From the “units_elec” sheet, you can find the installed capacity, generation from each technology, the utilization rate of different technologies etc., in the power grid (Check for the plots in the “units_elec_plot” sheet).
- From the “units_heat” sheet you can find the installed capacity, generation form each technology, the utilization rate of different technologies etc., for heating (Check for the plots in the “units_heat_plot” sheet).
- From the “units_hydrog” sheet you can find the installed capacity, generation form each technology, the utilization rate of different technologies etc., for heating (Check for the plots in the “units_hydrog_plot” sheet).
- From the “units_ev” sheet you can find the installed capacity, generation form each technology, the utilization rate of different technologies etc., for heating (Check for the plots in the “units_ev_plot” sheet).

There are several key flexibility issues in the presented system:

1. Power load shedding in nodes B & C.
2. Heat load shedding in node A.
3. Hydrogen load shedding in node C.
4. EV load shedding in all nodes.
5. High VRE curtailment in node A & C.

In the following activities, we will take some measures to address these flexibility issues by investing/adding different flexibility options and investigate how their implementation will affect the results.

Activity 2 – Demand response

Now, let's consider a plan to deploy a **demand response program**. This will include incentives to shift demand up or down. As reviewed in Lecture 6, demand response is modelled in FlexTool as *virtual generators*. The underlying logic is to represent demand-side actions as if they were occurring on the supply side.

- For **demand increase**, we use a negative capacity and price, which simulates additional generation needed to offset the "negative generation."
- For **demand decrease**, we define a positive variable cost. This cost should be lower than that of expensive generation or flexibility penalties, so that the system prefers to use demand reduction as a "supply option."

As previously done, let's proceed with:

1. Create a copy of **"Case-study3.xlsm"** and rename it **"Case-study4.xlsm."**
2. In the *Units* sheet, activate the **demand_incr** and **demand_decr** units by allocating capacities as shown in the figure below.
3. Run **Case 3** and **Case 4** under the **Base scenario.**

Add empty row

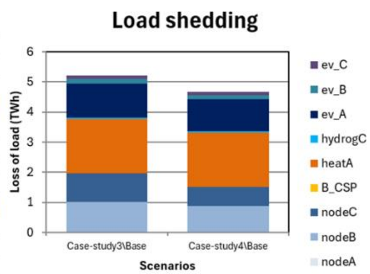
Choose one input option (none, fuel, cf profile, inflow **or** input grid+node)

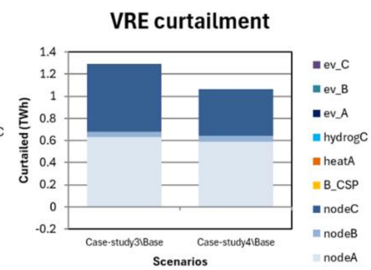
Output #1

	A	B	C	D	E	F	G	H	I	J
1	**unitGroup**	**unit type**	**fuel**	**cf profile**	**inflow**	**input grid**	**input node**	**output grid**	**output node**	**apacity (MW)**
18	Dem_inc	demand_incr						elec	nodeC	-150
19	Dem_dec	demand_decr						elec	nodeC	150

By examining the comparative results, we can see that both *demand_incr* and *demand_decr* technologies are utilized. In the *genUnit_elec* sheet, *demand_incr* is mostly activated during daytime hours when solar PV is generating energy, while *demand_decr* is more effective at night when there is no solar output. This approach has a positive impact by reducing curtailment and load shedding in node C. However, it does not appear to affect the other grids (heat, hydrogen, or EVs).

	A	B	C
1	Update sheets window	Case-study3	Case-study4
2		Base	Base
23	VRE share (% of annual demand)	69.25	69.91
24	Loss of load (% of annual demand)	5.616	4.329
25	-> ramp up constrained (% of annual demand)	0.2876	0.2727
26	Excess load (% of annual demand)	0	0
27	Insufficient reserves (% of reserve demand)	0	0
28	Insufficient inertia (% of inertia demand)	0	0
29	Curtailment (% of VRE gen.)	5.333	4.341
30	-> ramp down constrained (% of VRE gen.)	0.04758	0.03873
31	Peak load (MW)	5398.49	5398.49
32	Peak net load (MW)	4124.26	4124.26





Other trials could include adding these demand response technologies to nodes A and B. However, the range of capacity is limited, since in the real world users do not have significant flexibility to vary their demand (between 2% and 7% of peak load). In the following activities, we will explore sector coupling options, where electricity can be more broadly managed.

Activity 3 – Power to heat

As studied in Lecture 6, power to heat if done in the smart way can provide flexibility to the power grid and thermal storage with heat pump can provide load shifting services to the grid.

In this activity we want to investigate how adding thermal storage to the system will affect the flexibility issues in the power grid.

Instructions:

- First, please create a copy of **"Case-study4.xlsm"** and rename it **"Case-study5.xlsm."**
- Add Max Invest (MW) and Max Invest (MWh) to the thermal storage unit and Max Invest (MW) to heat pump in "unit" sheet in the new "Case-study5.xslm". As shown below.

- Add the “Case-study5.xslm” to the active input file (now you should have both “Case-study4.xslm” and “Case-study5.xslm”) and run the model in Invest mode.

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)
21	HeatPump	heat_pump				elec	nodeA	heat	heatA	320		300			
36	ThermalStorag	Thermal_sto						heat	heatA	0		500	0		4000

Questions:

How does adding thermal storage affect the loss of load and VRE curtailment in different nodes?

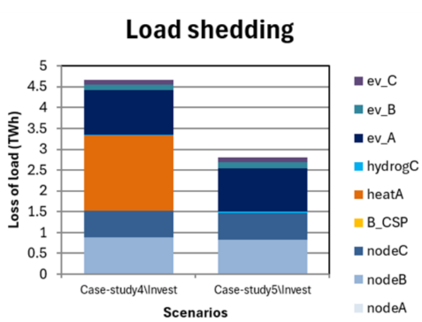
How does it affect the total system cost (Optimal objective)?

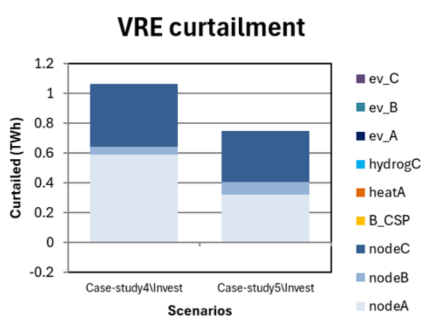
Does thermal storage affect loss of heating load?

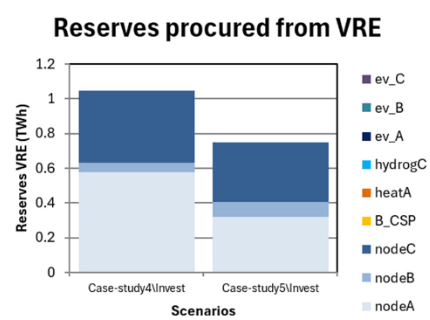
Try it:

- Check the system configuration and technology mix in “units_elec” and “units_heat” and “transfer_elc”.
- Check the utilisation rate of thermal storage.

	A	B	C
1	Update sheets window	Case-study4	Case-study5
2		Invest	Invest
22	General results	elec	elec
23	VRE share (% of annual demand)	69.91	70.8
24	Loss of load (% of annual demand)	4.329	4.194
25	-> ramp up constrained (% of annual demand)	0.2727	0.2882
26	Excess load (% of annual demand)	0	0
27	Insufficient reserves (% of reserve demand)	0	0
28	Insufficient inertia (% of inertia demand)	0	0
29	Curtailment (% of VRE gen.)	4.341	3.023
30	-> ramp down constrained (% of VRE gen.)	0.03873	0.03033
31	Peak load (MW)	5398.49	5398.49
32	Peak net load (MW)	4124.26	4124.26
237	General results	heat	heat
238	VRE share (% of annual demand)	0	0
239	Loss of load (% of annual demand)	18.11	0
240	-> ramp up constrained (% of annual demand)	0	0
241	Excess load (% of annual demand)	0	0
242	Insufficient reserves (% of reserve demand)		
243	Insufficient inertia (% of inertia demand)		
244	Curtailment (% of VRE gen.)		
245	-> ramp down constrained (% of VRE gen.)		
246	Peak load (MW)	2030.26	2030.26
247	Peak net load (MW)	2030.26	2030.26







1. Adding thermal storage provides load shifting over time in node A which as shown reduces the VRE curtailment and accordingly reserves requirements in node A and therefore the curtailment payments in the system.
2. Adding thermal storage has a very minor impact in power load shedding in points B & C.
3. Adding thermal storage solves the issue of heat load shedding in conjunction with additional heat pump capacity.

Although adding thermal storage and enabling power to heat flexibility option effectively reduces the VRE curtailment by load shifting over time, it doesn't solve all flexibility issues in all the nodes. In the next activity, we 'll continue to implement sector coupling measures.

Activity 4 – Power to hydrogen

In the previous activity, we found that heat shedding was effectively addressed by investing in additional heat pump capacity and thermal storage. In the case of hydrogen, we'll follow a similar approach by enabling investment in electrolyzers and hydrogen storage. However, we'll also allow the system to invest in fuel cell power plants for electricity production. This alternative can play additional utilility to handle surpluses of power increasing the flexibility of the system.

Instructions:

- First, please create a copy of **"Case-study5.xlsm"** and rename it **"Case-study6.xlsm."**
- Add Max Invest (MW) and Max Invest (MWh) to the hydrogen storage unit and Max Invest (MW) to electrolyzer and fuel cell in "unit" sheet in the new "Case-study6.xslm". As shown below.
- Add the "Case-study6.xslm" to the active input file (now you should have both "Case-study5.xslm" and "Case-study6.xslm") and run the model in Invest mode. Note: It will optimize power to heat options again.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
	Add empty row		Choose one input option (none, fuel, cf profile, inflow **or** input grid+node)					Output #1							
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)
27	Hydrogen	Electroyser				elec	nodeC	hydrog	hydrogC	200		200			
28	Hydrogen	Hydrogen_sto						hydrog	hydrogC	0		200	0		800
29	Hydrogen	fuelcell_PP				hydrog	hydrogC	elec	nodeC	0		200			

Questions:

How does adding hydrogen storage affect the loss of load and VRE curtailment in different nodes?

How does it affect the total system cost (Optimal objective)?

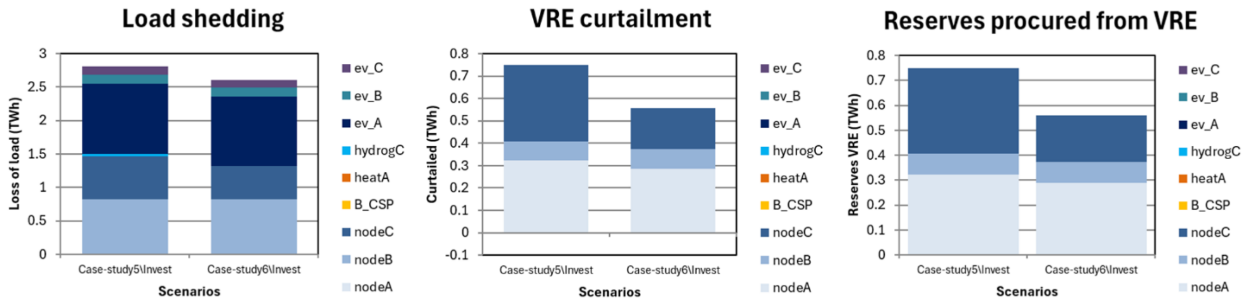
Is there any changes in the investment in the heat network?

Try it:

- Check the system configuration and technology mix in “units_elec” and “units_hydrog” and “transfer_elc”.
- Check the utilisation rate of electrolyzer and hydrogen storage.

	A	B	C
1	Update sheets window	Case-study5	Case-study6
2		Invest	Invest
22	General results	elec	elec
23	VRE share (% of annual demand)	70.8	71.35
24	Loss of load (% of annual demand)	4.194	3.758
25	-> ramp up constrained (% of annual demand)	0.2882	0.2528
26	Excess load (% of annual demand)	0	0
27	Insufficient reserves (% of reserve demand)	0	0
28	Insufficient inertia (% of inertia demand)	0	0
29	Curtailment (% of VRE gen.)	3.023	2.236
30	-> ramp down constrained (% of VRE gen.)	0.03033	0.02375
31	Peak load (MW)	5398.49	5398.49
32	Peak net load (MW)	4124.26	4124.26

	A	B	C
1	Update sheets window	Case-study5	Case-study6
2		Invest	Invest
303	General results	hydrog	hydrog
304	VRE share (% of annual demand)	0	0
305	Loss of load (% of annual demand)	2.849	0
306	-> ramp up constrained (% of annual demand)	0	0
307	Excess load (% of annual demand)	0	0
308	Insufficient reserves (% of reserve demand)		
309	Insufficient inertia (% of inertia demand)		
310	Curtailment (% of VRE gen.)		
311	-> ramp down constrained (% of VRE gen.)		
312	Peak load (MW)	203.026	203.026
313	Peak net load (MW)	203.026	203.026



1. Adding hydrogen storage provides load shifting over time in node C which as shown reduces the VRE curtailment and load shedding and accordingly reserve requirements in node C and therefore the penalty payments in the system.
2. Adding hydrogen storage has a very minor impact in power load shedding in nodes A & B.
3. Adding hydrogen storage solves the issue of hydrogen load shedding in conjunction with additional electrolyzer capacity. There is no need for fuel cell capacity.
4. The deployment of hydrogen technologies doesn’t affect the setting of heat network.

Hydrogen storage and electrolyzers have not been critical for solving the remaining flexibility issues of the power system. In the last activity of this hands-on, we’ll explore the subsystem of electric vehicles as a flexibility option.

Activity 5 – Power to electric vehicles

As studied in lecture 6, electric vehicles are represented in FlexTool as an additional grid. In our system, there are EV demands for all the three nodes. In each node, we have one different scheme of charging for EVs:

- In node A, we have unidirectional charging based directly on demand for mobility without options for flexible schedule.
- In node B, we have unidirectional charging with a flexible charging schedule because of there is a battery technology providing a temporal shift in the charging schedule.

- In node C, we have an approach of vehicle-to-grid (V2G) showcasing bidirectional charging with a flexible charging schedule. Apart of having a battery to provide a temporal shift in the charging schedule, there is also another charger that converts energy from the Electro-mobility grid (electric vehicles) back to the electricity grid.

Instructions:

- First, please create a copy of **"Case-study6.xlsm"** and rename it **"Case-study7.xlsm."**
- Add Max Invest (MW) and Max Invest (MWh) to the EV batteries and Max Invest (MW) to EV chargers in "unit" sheet in the new "Case-study7.xslm". As shown below.
- Add the "Case-study7.xslm" to the active input file (now you should have both "Case-study6.xslm" and "Case-study7.xslm") and run the model in Invest mode. Note: It will optimize power to heat and power to hydrogen options again.

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)
30	Charger	EV_Charger				elec	nodeA	ev	ev_A	1000		1000			
31	Charger	EV_Charger				elec	nodeB	ev	ev_B	100		1000			
32	Battery	EV_Battery						ev	ev_B	20		1000	100		10000
33	Charger	EV_Charger				elec	nodeC	ev	ev_C	100		1000			
34	Battery	EV_Battery						ev	ev_C	20		1000	100		10000
35	Charger	EV_2WayCharger				ev	ev_C	elec	nodeC	0		1000			

Questions:

How does adding EV infrastructure affect the loss of load and VRE curtailment in different nodes?

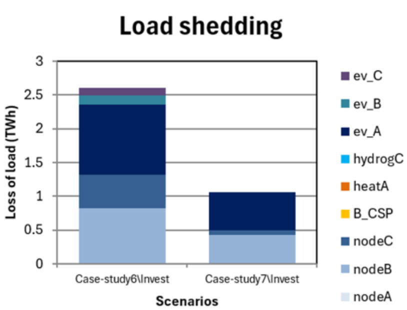
How does it affect the total system cost (Optimal objective)?

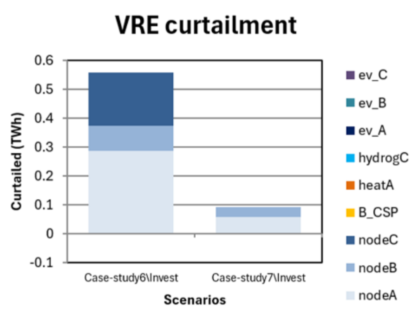
Is there any changes in the investment in the heat and hydrogen networks?

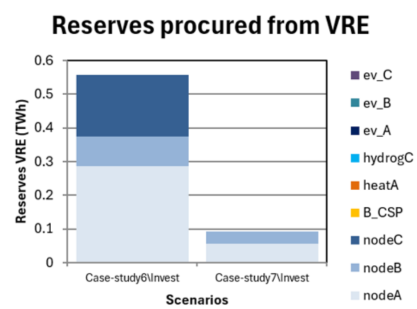
Try it:

- Check the system configuration and technology mix in "units_elec" and "units_ev" and "transfer_elc".
- Check the utilisation rate of EV batteries ad chargers including the 2Way_Charger.

	A	B	C
1	Update sheets window	Case-study6	Case-study7
2		Invest	Invest
22	General results	elec	elec
23	VRE share (% of annual demand)	71.35	72.68
24	Loss of load (% of annual demand)	3.758	1.416
25	-> ramp up constrained (% of annual demand)	0.2528	0
26	Excess load (% of annual demand)	0	0
27	Insufficient reserves (% of reserve demand)	0	0
28	Insufficient inertia (% of inertia demand)	0	0
29	Curtailment (% of VRE gen.)	2.236	0.3614
30	-> ramp down constrained (% of VRE gen.)	0.02375	0.003884
31	Peak load (MW)	5398.49	5398.49
32	Peak net load (MW)	4124.26	4124.26
368			
369	General results	ev	ev
370	VRE share (% of annual demand)	0	0
371	Loss of load (% of annual demand)	40.52	17.57
372	-> ramp up constrained (% of annual demand)	0	0
373	Excess load (% of annual demand)	0	0
374	Insufficient reserves (% of reserve demand)		
375	Insufficient inertia (% of inertia demand)		
376	Curtailment (% of VRE gen.)		
377	-> ramp down constrained (% of VRE gen.)		
378	Peak load (MW)	1568.03	1568.03
379	Peak net load (MW)	1568.03	1568.03







1. Adding EV infrastructure provides load shifting over time in all nodes which as shown reduces the VRE curtailment and load shedding and accordingly reserve requirements across the system and therefore the penalty payments in the system.
2. Adding EV infrastructure has very minor impact on the deployment of technologies in the heat and hydrogen grids.
3. Remaining load of shedding is present in EV in node A. It is also true for power load shedding in node B. Although almost marginal, curtailment occurs in nodes A and B.

Try it :

In order to address the remaining flexibility issues, you can explore additional alternatives:

1. By reviewing the *units_invest_plot* sheet, you will see that the shadow values of EV batteries and thermal storage are negative. This indicates that increasing investment in these technologies could potentially be positive.
2. Since we still have curtailment but load shedding in EV in node A at the same time, we could consider either storage technologies to balance electricity through time or increasing EV charging infrastructure in case it is a capacity adequacy issue. It can also be addressed by adding EV battery in node A. It means moving from unidirectional charging to flexible charging.
3. In node B, a similar history of simultaneous curtailment and load shedding indicates a possible unbalance in electricity through time. Therefore, adding a storage technology would be a first approach.