Assessing Power System Flexibility with IRENA FlexTool

Hands-on 3

Please use the following citation for:

- **This exercise**

Plazas-Niño, F. Hoseinpoori P., Kell A., & Hawkes A. (2025, April). Hands-on 3: Assessing power system flexibility with IRENA FlexTool (Version 1.0.). Climate Compatible Growth. DOI: 10.5281/zenodo.17070485

- **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) Run DemoModel-2.

2) Explore results of DemoModel-2.

3) Remove maximum investment limits.

Investigating and running the demo model 2

In this activity, we will continue exploring how to assess flexibility using the second demo model. Demo Model 2 consists of two files—one for 2017 and one for 2030—located in the *input data* folder.

The 2017 model represents the current situation, while the 2030 model reflects the capacity expansion plan. In 2030, the planned new investments include natural gas plants in Node C, wind power in Node A, and small shares of photovoltaics in all nodes.

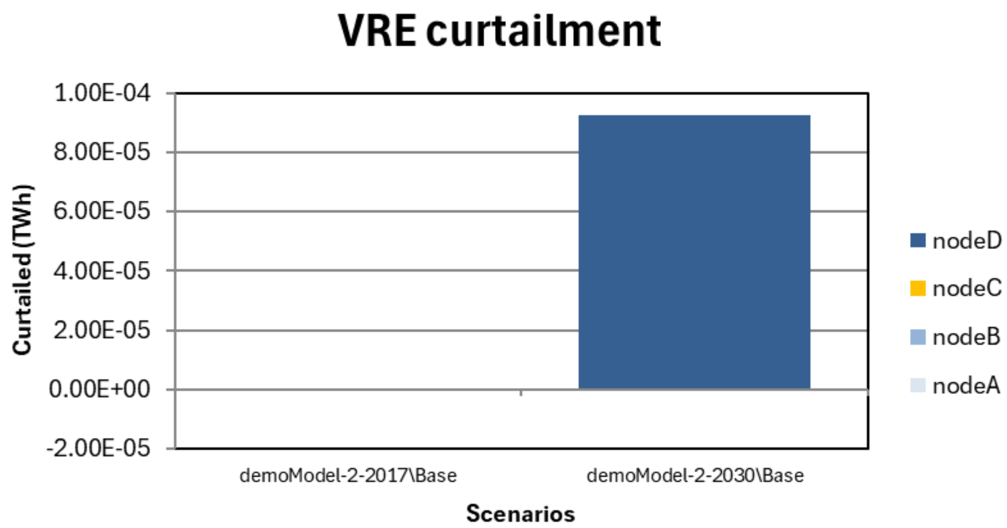
To run these models simultaneously for comparison, we will move (*toggle*) both **demoModel2-2017** and **demoModel2_2030** to the left side of the *input file* table, as shown in the figure below.

Active input files:		Inactive input files:
	<->	template.xlsm
	<->	
	<->	demoModel-1.xlsm
	<->	
demoModel-2-2017.xlsm	<->	
demoModel-2-2030.xlsm	<->	
	<->	
	<->	template-EVs.xlsm
	<->	
	<->	
	<->	
	<->	

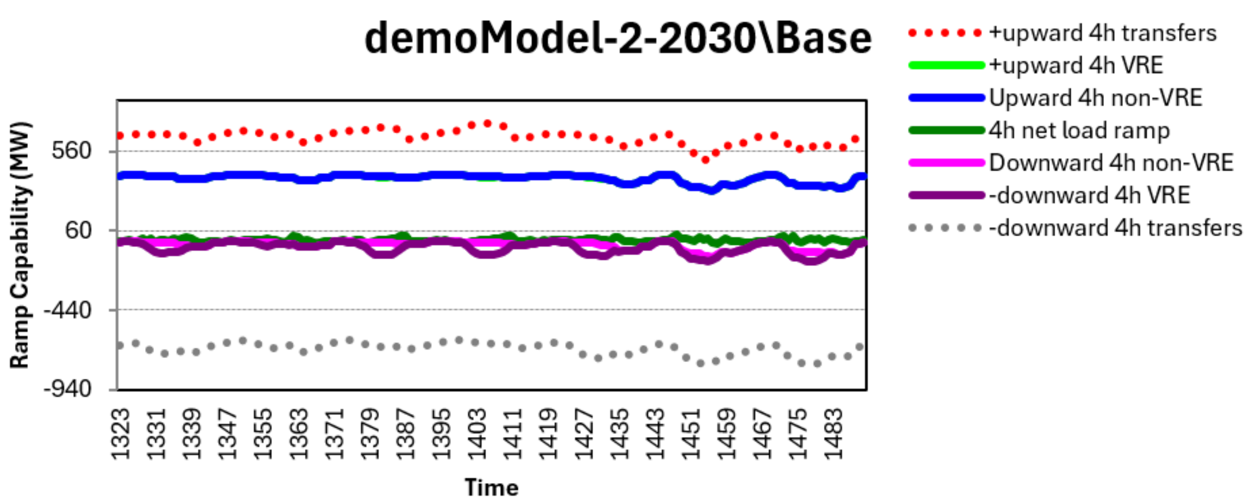
After running these models, we see no significant flexibility issues. The demo model shown in 2017 shows no issues whatsoever, whereas the model in 2030 shows no significant issues except for a very small curtailment. This can be seen by assessing the numbers in the table.

Update sheets window	demoModel-2-2017	demoModel-2-2030
General results	elec	elec
VRE share (% of annual demand)	4.981	8.988
Loss of load (% of annual demand)	0	0
-> ramp up constrained (% of annual demand)	0	0
Excess load (% of annual demand)	0	0
Insufficient reserves (% of reserve demand)	0	0
Insufficient inertia (% of inertia demand)		
Curtailment (% of VRE gen.)	-2.41E-06	0.007827
-> ramp down constrained (% of VRE gen.)	0	6.62E-09
Peak load (MW)	2071.46	2071.46
Peak net load (MW)	2047.44	2027.23
Flexibility issues	elec	elec
Loss of load (max MW)	0	0
Excess load (max MW)	0	0
Reserve inadequacy (max MW)	0	0
Insufficient inertia (TWs/a)	0	0
Curtailment (max MW)	0.000463404	1.65704
Curtailment (TWh/a)	-1.58E-08	9.24E-05
Model leakage (TWh/a)	0	0
Capacity inadequacy (max MW)	0	0
Spill (TWh/a)	0	0

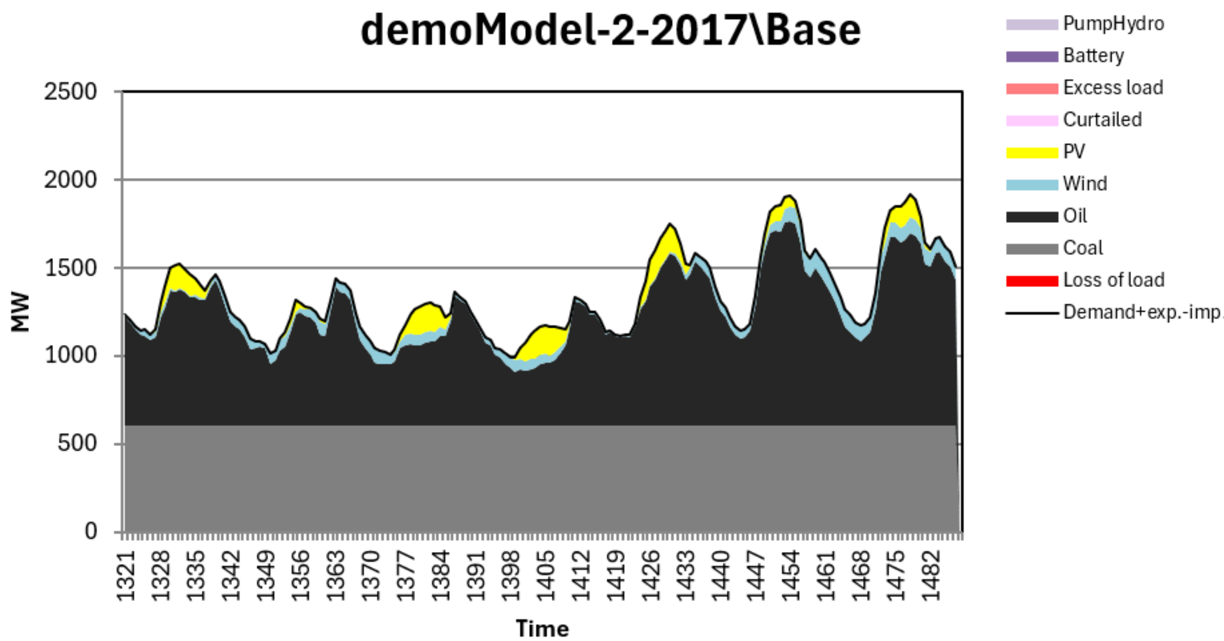
Based on the results, there was a small amount of curtailment in the 2030 model scenario. By looking at the node plot sheet, which is the top right-hand figure, we see that this curtailment occurs at node D.

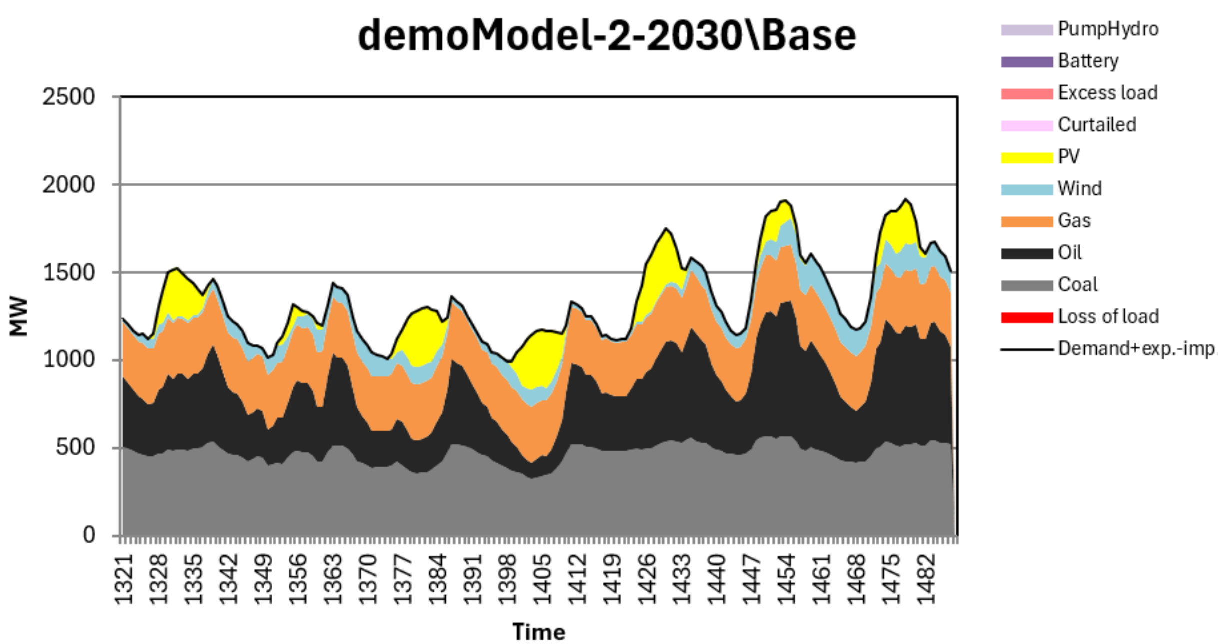


Other aspect that we can analyze is whether there is a sufficient ramping capability at the nodes. To do this, check the ramp room 1 hour elec node plot sheet. We see that all of the nodes have enough capability. In this sheet we have highlighted the ramp room 1 hour elec node B plot. We can see that node B at 2030 has a limited downward ramping capability within the node. However, this capability becomes very good when adding transfer connections as illustrated below.



The gen unit group elec plot sheet allows us to open the dispatch figures. A dispatch figure shows the contribution of each technology to the total electricity demand. So, for example, in the top figure, coal provides base load of just over 500 megawatts, and the rest of the demand for this week is met by oil, photovoltaics and a small bit of wind. The scroll bar allows one to change the week. The first week has the lowest demand, whereas the third week has the highest net load. The minimum loads of coal and gas units seem to be acceptable in the 2030 run. The small oil units should also be acceptable.





In a previous analysis, we saw that Node D has some curtailments. However, why do we have these curtailments? To find out we will do some further investigation.

First, we will look at the gen Unit elec sheet. We will then look at the 2030 scenario, node D. And then we will look for the variable renewable energy sources which have zero output. In this case, we will look at wind, because photovoltaics can have zero output in the absence of solar irradiance. We can see that between the hours of 1403 and 1406, for node D, there is zero output for wind. Therefore, there has been curtailment here.

13.7452	0.00314549	22.0454
9.00575	0.00381356	28.3531
7.6249	0.00398031	30.4956
7.74573	0	30.9829
7.82414	0	31.2966
7.76314	0	31.0525
9.97735	0.00293266	28.9164
16.4278	0.00249803	22.2829
25.2009	0.00184301	13.0809
[illegible]	[illegible]	[illegible]

During these hours, we can further investigate and see that the local non-synchronous share grows to 80% and therefore, the variable renewable energy generation is curtailed. For example, in the first row we have 30.9829/(30.9829+7.74573)=0.8.

The maximum non-synchronous share is defined in the input data. Specifically, in the grid node sheet and node groups sheet. We could increase this value to 0.9, for example, as a way to avoid these specific curtailments.

Exploring predefined investment runs

In this activity, we will evaluate additional scenarios by assessing predefined investment runs, similarly to what we did in hands-on 2 with demo1 model. Let's remember that predefined investment runs allow users to easily try alternative investment plans.

These can be selected in the FlexTool excel spreadsheet and run with the base scenario. For demo 2 model, we will evaluate two escenarios initially:

Demo2_storages: The storages scenario adds 5 megawatts of battery storage to node D. Node D is an island node with minor curtailments.

Demo2_PV: The photovoltaic scenario forces FlexTool to invest an additional 100 megawatts of photovoltaics in node A, 50 megawatts of photovoltaics in node B and 100 megawatts of photovoltaics in node C.

First, we need to modify the Sensitivity Definitions tab to add the corresponding constraints for each scenario. We need to add the invested capacity for each technology and scenario in the Units sheet, as described previously. Use the figure below as a reference. **Note:** Remember to click Add Empty Row before entering the information for each new scenario.

Add empty row

Can have only one input option (none, fuel, cf profile, inflow **or** input grid+node). Check carefully with input file if changing here.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
48	**Scenario definitions units:**	Sheet	unitGroup	unittype	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)	storage start	storage finish
49	demo1_invest_storages	units		battery						elec	nodeA				0.01				
50	demo1_invest_storages	units		battery						elec	nodeB				0.01				
51	demo1_invest_storages	units		battery						elec	nodeC				0.01				
52	demo1_invest_all	units		battery						elec	nodeA				0.01				
53	demo1_invest_all	units		battery						elec	nodeB				0.01				
54	demo1_invest_all	units		battery						elec	nodeC				0.01				
5	demo2_storages	units		battery						elec	nodeD		50			50			
5	demo2_PV	units		PV						elec	nodeA		100						
5	demo2_PV	units		PV						elec	nodeB		50						
5	demo2_PV	units		PV						elec	nodeC		100						

Finally, we can run the scenarios along with base case by selecting the appropriate model (demo2-2030) and scenarios (base, storages and PV) as shown below.

Active input files:		Inactive input files:
	<->	template.xlsm
	<->	
	<->	demoModel-1.xlsm
	<->	
	<->	demoModel-2-2017.xlsm
demoModel-2-2030.xlsm	<->	
	<->	
	<->	template-EVs.xlsm
	<->	
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	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	

Active scenarios:		Inactive scenarios:
Base	<->	
	<->	Invest
	<->	
	<->	demo1_invest_transCap
	<->	demo1_invest_genCap
	<->	demo1_invest_storages
	<->	demo1_invest_all
	<->	
demo2_storages	<->	
demo2_PV	<->	
	<->	demo2_windGas
	<->	
	<->	
	<->	template_storageMW
	<->	template_storageFree
	<->	template_changeDemand
	<->	template_changeTransferCa
	<->	
	<->	
	<->	
	<->	

Activity: According to the scenario results, answer the following questions:

- Did storage capacity help with the curtailments in 'nodeD'?
- Which scenario had the lowest costs?
- Did curtailments increase when the PV capacity increased from 300 MW to 550 MW?

Free investment run

If we examine the input data of the demo-2-2030 model, we can see that maximum investment levels are defined for most technologies in the *units* sheet, including batteries. For instance, PV has an investment cap of 500 MW in nodes A, B, and C, and 100 MW in node D. The same applies to transmission capacity, as indicated in the *nodeNode* sheet.

This means that, when running the model in invest mode, it will be able to allocate new investments across these technologies.

We will now proceed to activate both the base and invest scenarios for the *demo-2-2030* input file and run them, as illustrated in the figure below.

Active input files:		Inactive input files:
	<->	template.xlsm
	<->	
	<->	demoModel-1.xlsm
	<->	
	<->	demoModel-2-2017.xlsm
demoModel-2-2030.xlsm	<->	
	<->	
	<->	template-EVs.xlsm
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	
	<->	

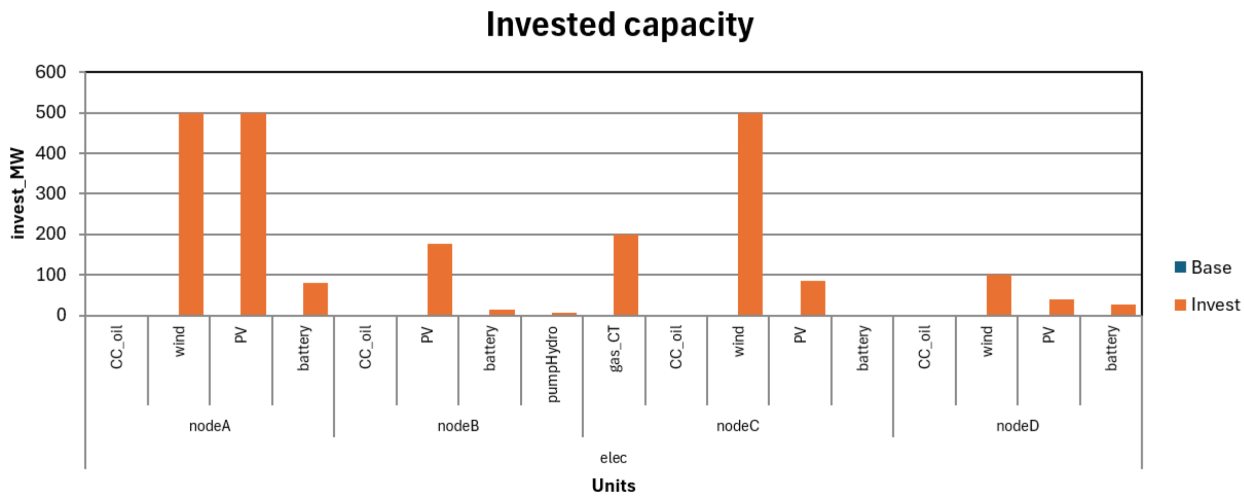
Active scenarios:		Inactive scenarios:
Base	<->	
Invest	<->	
	<->	
	<->	demo1_invest_transCap
	<->	demo1_invest_genCap
	<->	demo1_invest_storages
	<->	demo1_invest_all
	<->	
	<->	demo2_storages
	<->	demo2_PV
	<->	demo2_windGas
	<->	
	<->	
	<->	template_storageMW
	<->	template_storageFree
	<->	template_changeDemand
	<->	template_changeTransferCa
	<->	
	<->	

By reviewing the **summary_D** sheet, we begin by verifying the newly invested capacities through comparison with the base case. The corresponding values are highlighted in red in the figure below. More transmission along with renewables + storage are key in the investment strategy.

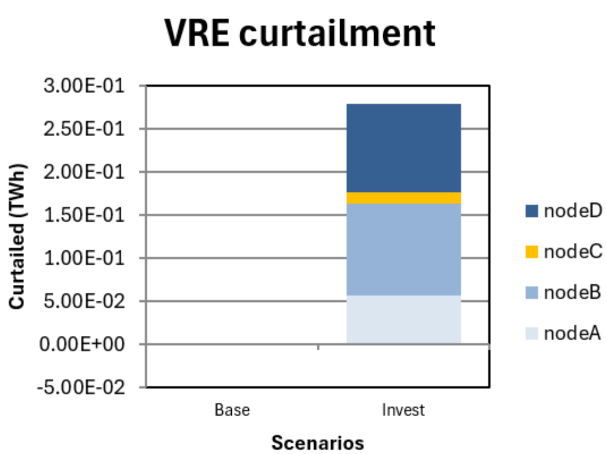
	A	B	C
1	Update sheets window	demoModel-2-2030	demoModel-2-2030
2		Base	Invest
79	Unit type	Capacity (MW)	Capacity (MW)
80	ST_coal	600	600
81	gas_CC	300	300
82	gas_CT	100	300
83	CC_oil	1580	1580
84	wind	250.01	1350.01
85	PV	300	1101.68
86	battery	5.03	123.599
87	pumpHydro	10	17.83

	A	B	C
1	Update sheets window	demoModel-2-2030	demoModel-2-2030
2		Base	Invest
109	Transfer	Capacity (MW)	Capacity (MW)
110	nodeA - nodeB	250	369.438
111	nodeB - nodeA	250	369.438
112	nodeB - nodeC	200	624.926
113	nodeC - nodeB	200	624.926

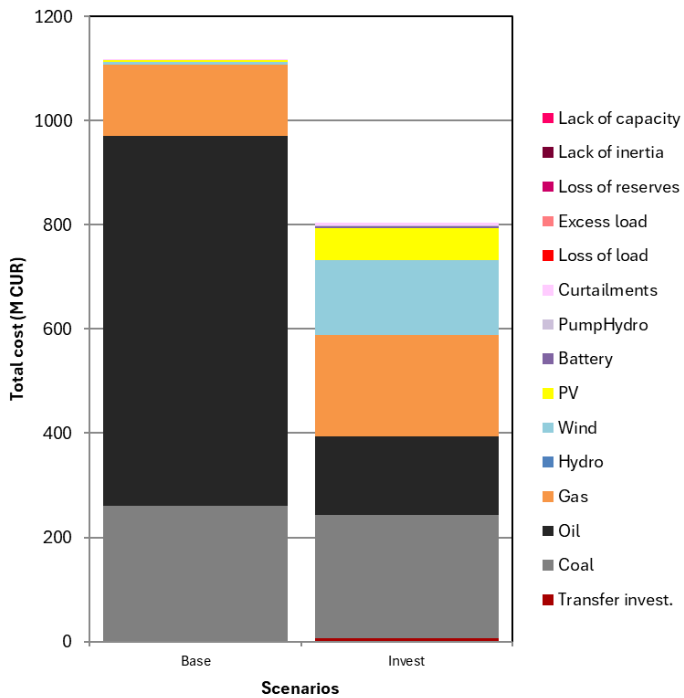
As analyzed previously, we can obtain node-level details by exploring the **units_invest_plot** sheet. The results show wind and PV investments across all nodes. Batteries are deployed everywhere except in node C, where natural gas combustion turbines are installed instead. Additionally, some pumped hydro capacity is invested in node B.



In the **summary_D** sheet, we can observe that the share of VRE increases significantly, rising from 9% in the base scenario to 39% in the invest scenario. This higher penetration of renewable energy leads to an increase in curtailment, which grows from 0% to 5.4%. The curtailment is distributed across all nodes, as illustrated in the **node_plot** sheet.

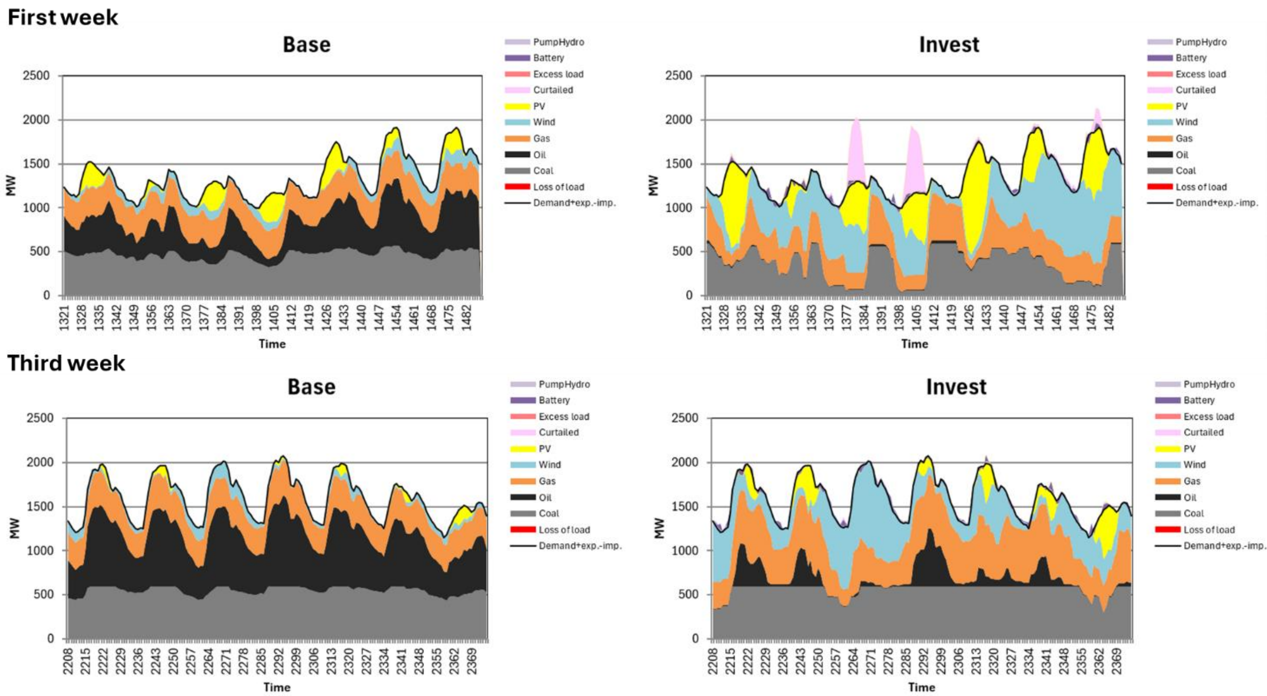


Despite the higher curtailment, the total cost of the invest scenario is nearly 30% lower than that of the base scenario. Looking at the **cost_unitGroup_plot** sheet, we can see that this outcome is driven by the fact that the capital investment in solar and wind is still lower than the fuel costs required to run oil, coal, and natural gas plants. Moreover, the penalty associated with curtailment is relatively minor, resulting in no significant impact on the overall system cost.

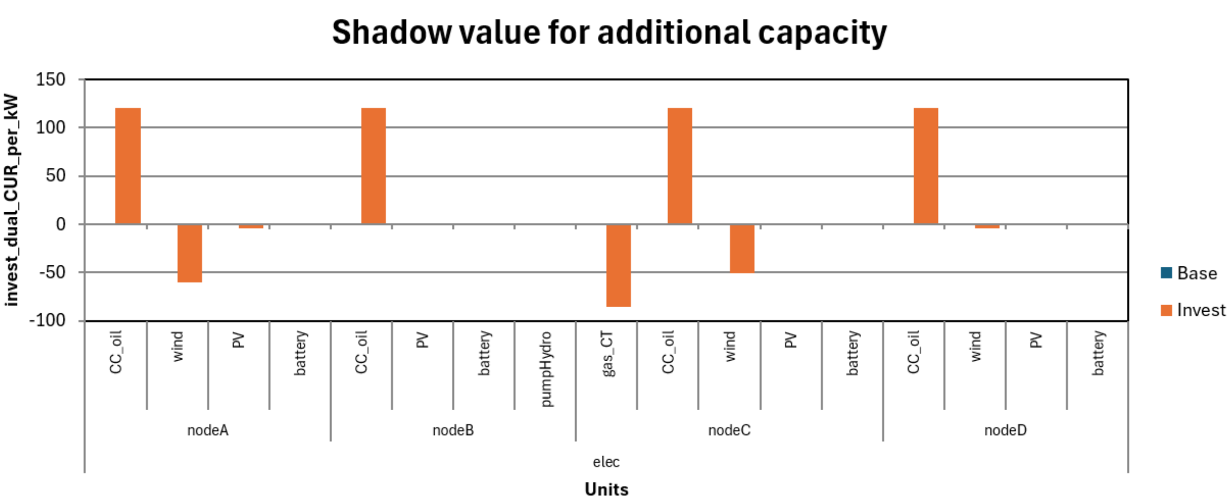


In terms of generation, the **genUnitGroup_elec_plot** sheet allows us to examine the dispatch groups for representative weeks. In the example below, we compare the first week, which has low demand, with the third week, which has high demand. Both the natural gas combined cycle unit and the gas turbine units appear flexible enough to operate within the modeled ramps and minimum load constraints, depending on their actual unit sizes. By contrast, the minimum load of coal-fired power plants in the invest scenario seems unrealistically low and would likely require closer attention. In practice, stricter minimum load constraints could limit investments in coal while favoring natural gas and VRE technologies.

Nevertheless, the results clearly show that it is cost-effective to replace high-cost oil generation with wind, solar, and natural gas. Determining the precise mix and amounts, however, would require further detailed studies.



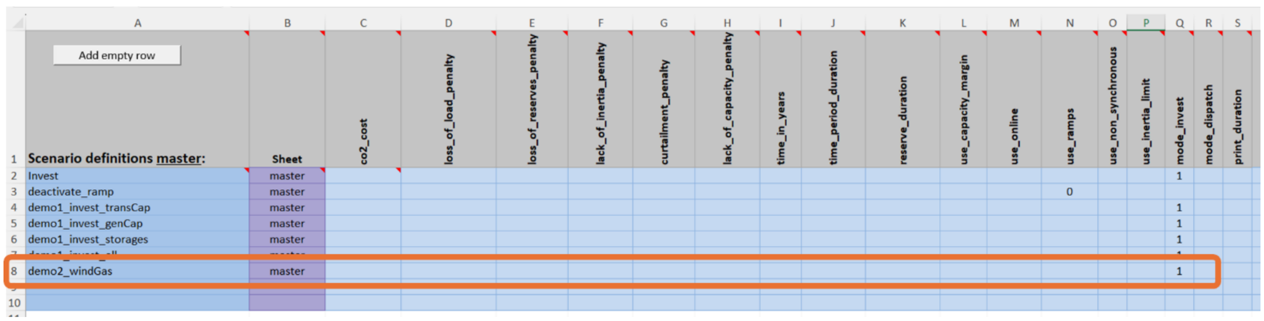
One final aspect to review is the shadow value of investments, as studied previously. Returning to the **units_invest_plot**, we can observe the values as illustrated below. Both gas and wind show negative shadow values, meaning that additional investments in these technologies would reduce the total system cost. However, their expansion is constrained by the investment limits defined in the input data.



Removing max investment limits in wind and gas

In this next activity, we will remove the maximum investment limits for wind power and gas turbines. There is a predefined scenario named **demo2_windGas**. As in previous exercises, we first need to add the corresponding constraints in the sensitivity definitions sheet.

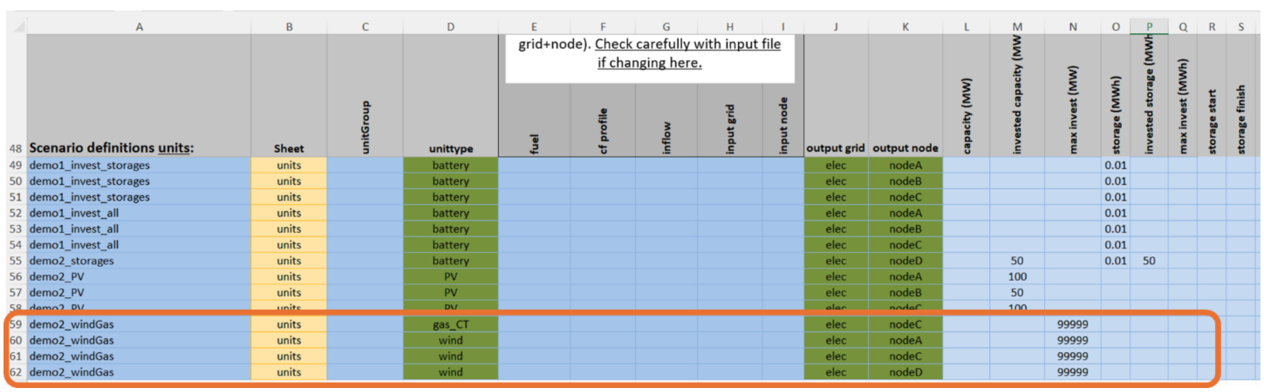
The first step is to activate the invest mode in the master sheet, as illustrated below.



Add empty row

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
1	Scenario definitions master:	Sheet	co2_cost	loss_of_load_penalty	loss_of_reserves_penalty	lack_of_inertia_penalty	curtailment_penalty	lack_of_capacity_penalty	time_in_years	time_period_duration	reserve_duration	use_capacity_margin	use_online	use_ramps	use_non_synchronous	use_inertia_limit	mode_invest	mode_dispatch	print_duration
2	Invest	master															1		
3	deactivate_ramp	master												0					
4	demo1_invest_transCap	master															1		
5	demo1_invest_genCap	master															1		
6	demo1_invest_storages	master															1		
8	demo2_windGas	master															1		
10																			

To eliminate the maximum investment limits, we will adjust the units sheet by assigning a very high value (e.g., 99,999) equivalent to leave the field unconstrained in the *max invest* column for the technologies that showed negative shadow values. Your input should resemble the reference image provided.



grid+node). Check carefully with input file if changing here.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
48	Scenario definitions units:	Sheet	unitGroup	unittype	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)	storage start	storage finish
49	demo1_invest_storages	units		battery						elec	nodeA				0.01				
50	demo1_invest_storages	units		battery						elec	nodeB				0.01				
51	demo1_invest_storages	units		battery						elec	nodeC				0.01				
52	demo1_invest_all	units		battery						elec	nodeA				0.01				
53	demo1_invest_all	units		battery						elec	nodeB				0.01				
54	demo1_invest_all	units		battery						elec	nodeC				0.01				
55	demo2_storages	units		battery						elec	nodeD		50		0.01	50			
56	demo2_PV	units		PV						elec	nodeA		100						
57	demo2_PV	units		PV						elec	nodeB		50						
59	demo2_windGas	units		gas_CT						elec	nodeC			99999					
60	demo2_windGas	units		wind						elec	nodeA			99999					
61	demo2_windGas	units		wind						elec	nodeC			99999					
62	demo2_windGas	units		wind						elec	nodeD			99999					

Once these constraints have been added, please **run the three models** for comparison.

Activity:

Based on the results, follow the same analytical process as in the previous activity. Compare the scenarios in terms of:

- **Installed capacities** (per technology and per node)
- **Flexibility aspects** (loss of load, curtailment, ramping)
- **System costs** (investment vs. operational vs. penalties)
- **Generation mix** (dispatch patterns across representative weeks)
- **Shadow values**