Energy and Flexibility Modelling

Hands-on 14: Modelling flexibility options in FlexTool

Pease use the following citation for this exercise:

Please download the required files from this link: https://doi.org/10.5281/zenodo.4617028

Learning outcomes

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

1) Identifying the flexibility issues in the case study

2) Implementing different flexibility options in FlexTool

3) Adding thermal storage and transmission to FlexTool

4) Comparing investments in different flexibility options and assess their impact and cost-effectiveness

Activity 1

We want to identify the flexibility issues in a system with high penetration of variable renewables in the first activity. The case study represents a system with three nodes.

Note: The numbers used in this case study are not representing reality.

Please do the following steps:

1. Download the input file named "Case-study.xlsm" from the link provided above.

2. Save the "Case-study.xlsm" in the root folder "InputData\FlexTool-v2.0"
3. Open the Flextool main interface (the "flexTool.xlsm" excell file) and add "Case-study.xlsm" to the *Active input files*.
4. Add *Base* scenario to the Active Scenarios
5. Run the model and wait for the result file to open

In the "summery_D" sheet in the result file, try to identify the flexibility issues by checking the values represented bellow:

Update sheets window	Case-study
	Base
Status	Optimal
VRE share (% of annual demand)	38.17
Loss of load (% of annual demand)	35.54
Excess load (% of annual demand)	0
Insufficient reserves (% of reserve demand)	0
Insufficient inertia (% of inertia demand)	0
Curtailment (% of VRE gen.)	3.964
Loss of load (max MW)	1688.19
Excess load (max MW)	0
Reserve inadequacy (max MW)	0
Insufficient inertia (TWs/a)	0
Curtailment (max MW)	983.581
Curtailment (TWh/a)	0.529473

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 heat? What do you think the reason is?
- Which node has the highest load shedding for power?
- Which node has the highest VRE curtailment?
- Which node has the highest outgoing power transfer?

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).
- You can find the information about the power transferred between the nodes in the "transfer_elc" sheet (Check the plots in the "transfer_elect_plot" sheet).

There are a couple of key flexibility issues in the presented system:

1. Power load shedding in nodes B & C.
2. Heat load shedding in node A
3. 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

The first step to resolve the flexibility issues is see if further investment in the new capacities of exisitng technologies/transmission will resolve the flexibility issues.

- Open the case study input file and in the "unit_type" and "nodeNode" sheets and review the maximum investment allowed for each technology/transmission line.
- Close the input file and add *Invest* to the active scenarios and run the model and wait for the result file to be created (please keep the *Base* scenario in the active scenarios for comparing the results).

Question:
Did investment in new capacities of existing technologies reduced 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 "summery_D" sheet and then go to the "node_plot" sheet and compare the load shedding and VRE curtailment for *Base* and *Invest* scenarios.

Load shedding — VRE curtailment — Reserves procured from VRE
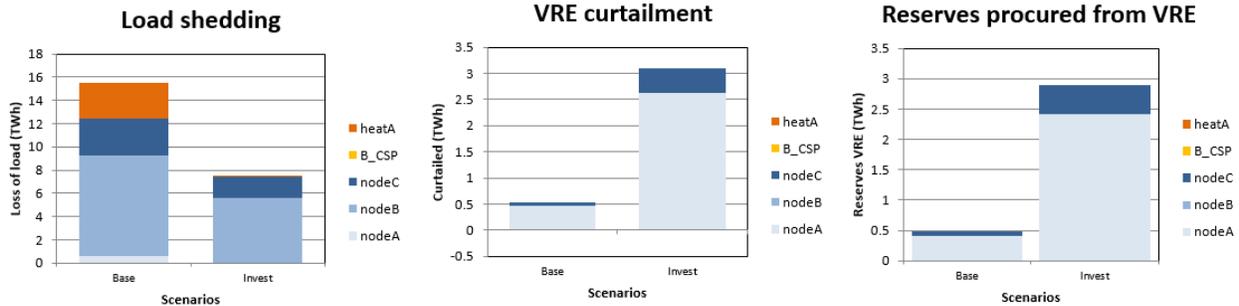
1. Investment in new capacities of existing technologies has reduced total system cost.
2. Investment in new capacities of existing technologies has reduced the loss of load in Point B.
3. Investment in heating generation technologies, in this case heat pumps, have eliminated the loss of heat load in point A.
4. Increased investment in renewable generation technologies has increased the VRE curtailment in nodes A and C the invest mode, although there is load shedding in nodes B and C. 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 "units_heat" and "transfer_elc"

It the flexibility lecture, it was discussed that power to heat, if implemented in a smart way, can provide flexibility to the power grid. Heat pumps integrated with thermal storage can provide load shifting services to the grid by running at the times that there is excess renewable output in the grid and store the hot water in the storage tanks.

Activity 3

It flexibility lecture it was discusses that 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.

To do so follow the steps discussed in the flexibility option lectures and add a thermal storage unit in the Input file

- Make a copy of "Case-study.xslm" file in the InputData folder and rename it to "Case-study-heat.xslm"
- Add a thermal storage unit in "unit" and "unit_type" sheet in the new "Case-study-heat.xslm". As shown bellow.
- Add the "Case-study-heat.xslm" to the active input file (now you should have both "Case-study.xslm" and "Case-study-heat.xslm") and run the model.

unit type	efficiency	min load	eff at min load	ramp up (p.u. per min)	ramp down (p.u. per min)	O&M cost/MWh	availability	max reserve	inertia constant (MWs/MW)	fixed cost/kW/year	inv.cost/kW	inv.cost/kWh	fixed kW/kWh ratio	conversion eff	startup cost	min uptime (h)	min downtime (h)	eff charge	self discharge loss	lifetime	interest	annuity	non synchronous
Thermal_storage	1.00			1.00	1.00		1.00	0.00			0	10						1.00	0.00	20	0.08	0.102	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)
Thermalstorage	Thermal_storage						heat	heatA	500		2500	40000

Choose one input option (none, fuel, cf profile, inflow **or** input grid+node) — Output #1

Questions:

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

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

Does thermal storage doesn't affect loss of heating load in the Base scenarios?

Update sheets window	Case-study	Case-study	Case-study-Heat	Case-study-Heat
	Base	Invest	Base	Invest
Status	Optimal	Optimal	Optimal	Optimal
Optimal objective	1.55E+11	7.41E+10	1.54E+11	7.38E+10
...Curtailment payments (M CUR)	26.47364038	155.1863756	25.26952735	105.3269259
VRE share (% of annual demand)	38.17	49.21	38.24	48.93
Loss of load (% of annual demand)	35.54	21.18	35.58	21.18
Excess load (% of annual demand)	0	0.02157	0	0
Insufficient reserves (% of reserve demand)	0	0	0	0
Insufficient inertia (% of inertia demand)	0	0	0	0
Curtailment (% of VRE gen.)	3.964	18.02	3.776	12.3
Loss of load (max MW)	1688.19	1390.19	1688.19	1390.19
Excess load (max MW)	0	-153.169	0	0
Curtailment (max MW)	983.581	2237.13	896.495	1822.24
Curtailment (TWh/a)	0.529473	3.10373	0.505391	2.10654
Model leakage (TWh/a)	-0.00913161	-0.0480479	-0.00913161	-0.0280732
Capacity inadequacy (max MW)	0	0	0	0
Spill (TWh/a)	0	0.325747	0	0
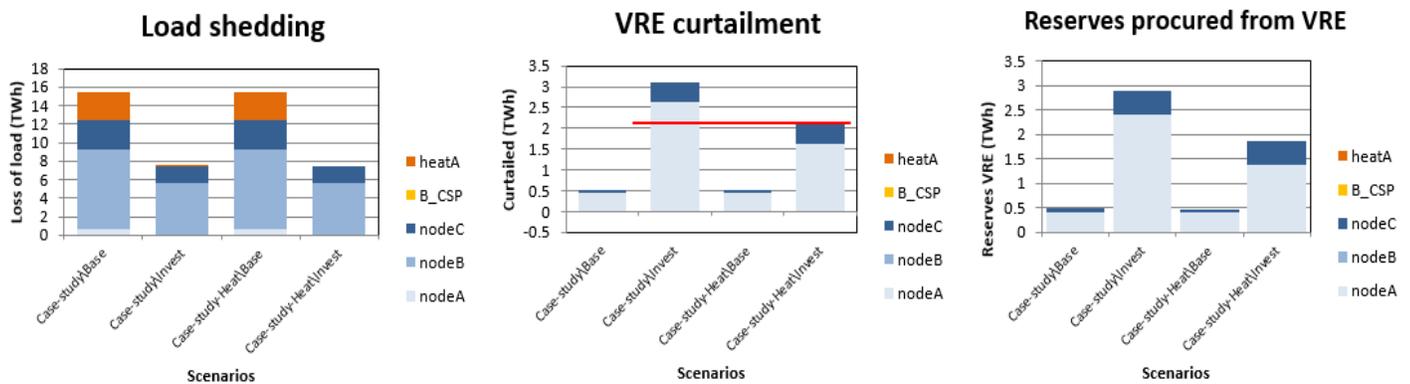
Load shedding — **VRE curtailment** — **Reserves procured from VRE**

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 both Invest and Base scenarios.

1. Adding thermal storage provide load shifting over time in node A which as shown reduces the VRE curtailment and accordingly reserve requirements in point A and therefore the curtailment payments in the system.
2. Adding thermal storage doesn't have (very minor) impact in power load shedding in points B & C.
3. Adding thermal storage doesn't reduce the heat load shedding in the base case because the loss of heat load in that case is due to insufficient heat pump capacity.

Although adding the thermal storage and enabling power to heat flexibility option effectively reduces the VRE curtailment by load shifting over time, but it doesn't solve all flexibility issues in all the nodes. In the next activity, we try load balancing over space between nodes and adding more transmission capacity.

Activity 4

We investigate impact of investing in additional transmission in two steps:

Step 1: In the first step we want to investigate if additional investment in expanding the existing transmission will solve the flexibility issues. To do so:

- Make a copy of "Case-study-heat.xslm" file in the InputData folder and rename it to "Case-study-heat-trans.xslm".
- From the "nodeNode" sheet increase the maximum investment in existing transmission to 1000 MW.
- Add the "Case-study-heat-trans.xslm" to active input data list and run the model.
- (you can remove Base from active scenarios if you want to reduce the number of scenarios generated. That make the comparison between different scenarios easier.)

Questions:

Does increased investment in existing transmission capacity solve all flexibility issue in all the nodes?

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

Transfers out of the node / Transfers to the node
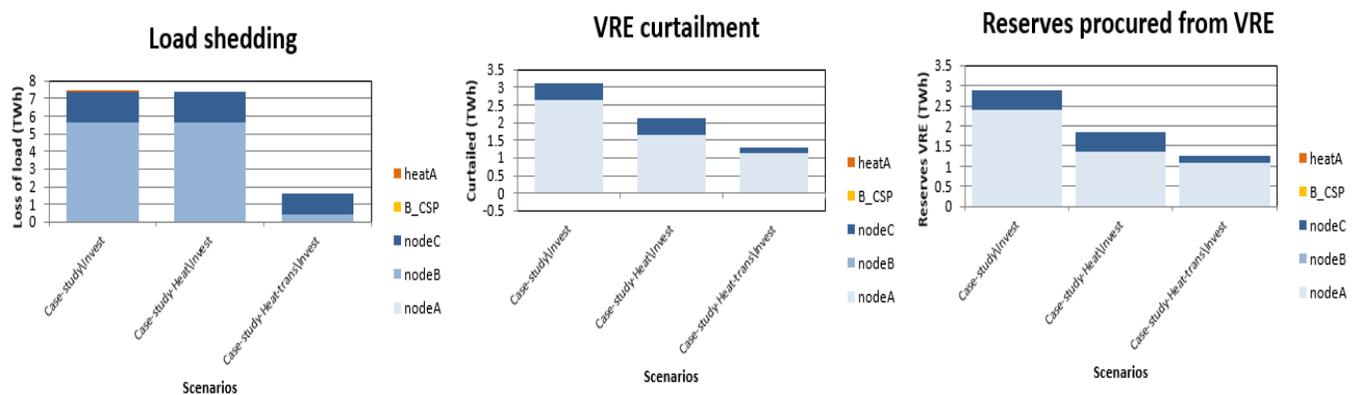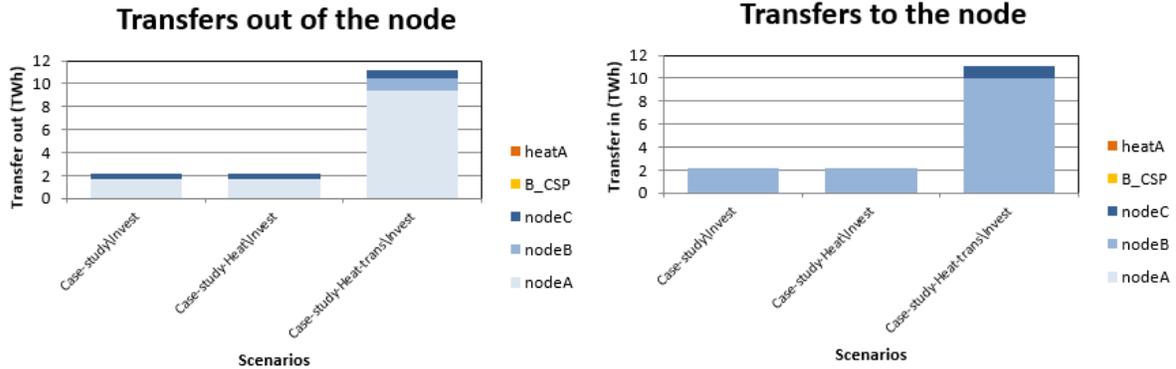
In the "node_plot" sheet check how additional investment in transmission will affect the Load shedding, VRE curtailment and power balancing between the nodes. Check the power transferred between the nodes and the utilisation rate of transmission lines.

> Increased investment in transition between node A and B and node B and C, reduces the loss of load in node B and also reduces the renewable curtailment in point A. However it only partially reduces the loss of load in point C.

Step 2:

In this step we want to add a new transmission line between points A and C: since we still have high VRE curtailment in node A and also a small amount of loss of load in Point C We want to add new transmission link between point A and C.

Add a transmission line between point A and C in "nodeNode" sheet with zero Capacity and 1000 MW max investment and run the model again.

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
elec	nodeA	nodeB	150	150		1000	0.01	100	50	0.08	0.082	0	
elec	nodeB	nodeC	100	100		1000	0.01	100	50	0.08	0.082	0	
elec	nodeA	nodeC	0	0		1000	0.01	100	50	0.08	0.082	0	

Questions:

Does increased investment in existing transmission capacity solve all flexibility issue in all the nodes?

How the power transferred through other transmission lines? (check "transfer_elc")
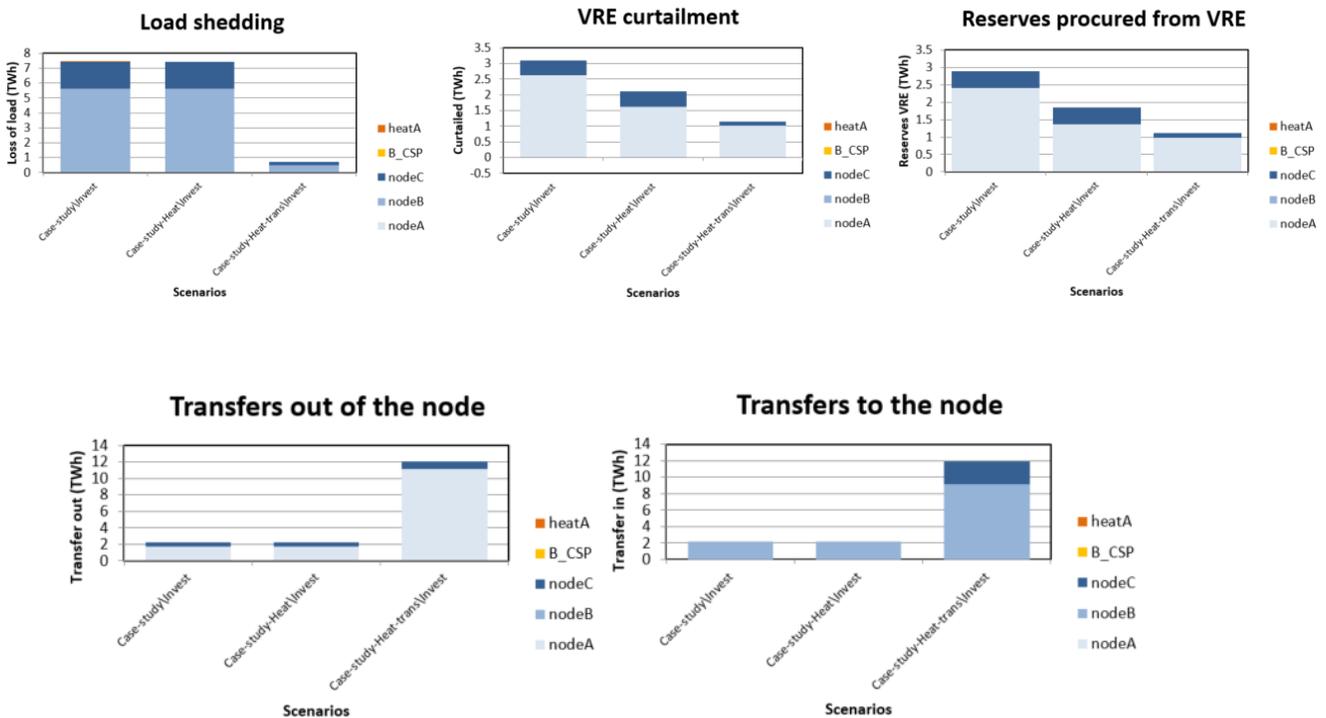
1. Investment in additional capacity between nodes A and C seems to effectively reduce the loss of load in node C. However, it doesn't have a major impact on VRE curtailment in node A compared to step 1.
2. The additional line will reduce the power transferred from node B to C (rightward) significantly. Both transmission lines BC and AC have low capacity factors that indicate the level of investment exceeds what is required and could be reduced.

Try it :

Try adding other flexibility options such as demand-side management and increasing investment in storage units in node A and try to see if these options will further reduce the VRE curtailment in Node A.

Note: To add demand repose in point A or B you can just copy the existing Demand response units and change the output grid to the desired node, and change installed capacity and Max Investment. You can also increase the investment in demand-side management in point C.

Note: If none of the options works, this means there is excess investment in VRE units that exceeds demand. To deal with this issue, you can either reduce investment in renewables or try to make additional demand by adding EV network or Hydrogen network to the system.

Please check the input file template EV and check the sheets: "nodeGroup", "gridNode", "unit_type", "unitGroup", "units" and "ts_energy" to see how to add an EV network to the system in a specific node.

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)	storage start	storage finish	reserve increase ratio	use efficiency time series	fix unit generation	use min generation	use max generation	use min online	inflow multiplier
Hydro	Hydro_RES			nodeA_RES			elec	nodeA	300		200	300000		0									1
Hydro	Hydro_ROR			nodeA_ROR			elec	nodeA	150		0												1
Battery	battery						elec	nodeA	100		50	200											
Dem_inc	demand_incr						elec	nodeC	-30		100												
Dem_dec	demand_decr						elec	nodeC	40		100												
Dem_inc	demand_incr						elec	nodeA	-30		100												
Dem_dec	demand_decr						elec	nodeA	40		100												