



# Energy and Flexibility Modelling

## Hands-on 16: Linking FlexTool and OSeMOSYS

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Please download the required files from this link: <https://doi.org/10.5281/zenodo.4616943>

## Learning outcomes

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

- 1) Assess the flexibility of the system developed in OSeMOSYS
- 2) Add data from OSeMOSYS into FlexTool
- 3) Rebuild the system developed in OSeMOSYS in FlexTool
- 4) Perform a sensitivity analysis and investigate different investment options

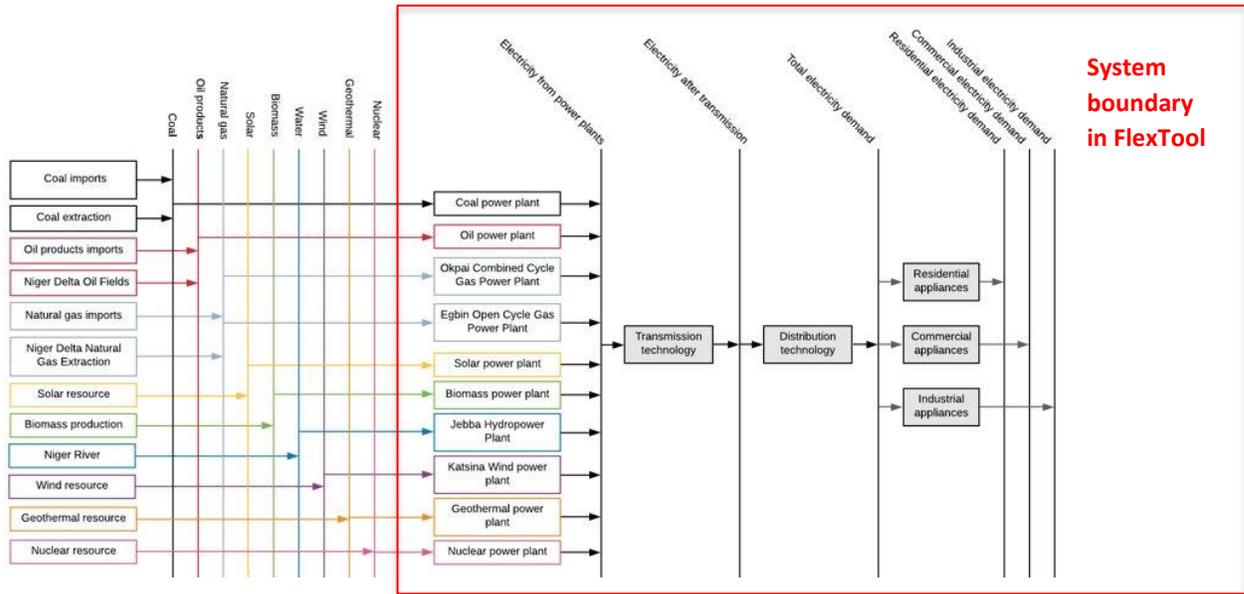
## Broader context

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In the first part of this course, you were introduced to OSeMOSYS and how to use it to develop a whole system model for a region. In the second part of the course, you became familiar with the concept of system flexibility and were then introduced to FlexTool and used it to assess the flexibility of a system. Both of these tools have strengths across different features. In this exercise, we want to show you how to link these two tools to address different aspects of the energy system transition in a region.

For that purpose, we will do a flexibility assessment of the power system that was developed in OSeMOSYS from the first part of the course.

To do so, you must first rebuild the system that was developed in OSeMOSYS, in FlexTool. It is important to note the boundaries of the systems developed in OSeMOSYS are different from the system in FlexTool. OSeMOSYS covers the whole system from fuel production, energy conversion, transportation and energy demand, while FlexTool does the flexibility assessment in the network and power generation level and does not cover the upstream fuel production and processing units and networks (Red Box).



We will rebuild the power system developed in the OSeMOSYS in FlexTool step by step in activity 1 and then conduct a flexibility assessment in activity 2. Please download the template input file provided and fill it out according to the figures in Activity 1. You can use different names. However, it is important to keep consistency in the naming of units and nodes etc., otherwise, you will receive an error when running the model.

# Activity 1

In this activity, we rebuild the power system developed in OSeMOSYS in FlexTool. To do so, we will add the system data that was obtained by OSeMOSYS (as discussed in Hands-on exercise 11) to the FlexTool input file in three steps:

master	gridNode	nodeGroup	unit_type	fuel	unitGroup	units	nodeNode	ts_cf	ts_inflow	ts_import	ts_energy	ts_reserve_node	ts_reserve_nodeGroup	ts_unit	ts_time
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**Step 1:** Adding wholes system data, defining technologies, grids and nodes and defining the groupings (Filling the purple sheets).

**Step 2:** Adding the time series (Filling the green Sheets).

**Step 3:** Building the system structure by linking grids, nodes and technologies (Filling the yellow sheets).

## Step 1: Filling the purple sheets

1.1 The **master** sheet includes data on parameters and settings affecting the whole model. Here you can:

Activate or deactivate system constraints such as capacity margin required, inertia limit requirements etc.

Specify the penalty cost such as CO<sub>2</sub> emission cost, loss of load penalty: lack of Inertia penalty etc. Please note that these data are region-specific and should be set according to the data from the studied region. Since our system doesn't represent any specific region, we will use the default values here.

parameter	value
co2_cost	20
loss_of_load_penalty	100000
loss_of_reserves_penalty	20000
lack_of_inertia_penalty	30000
curtailment_penalty	50
lack_of_capacity_penalty	5000
time_in_years	1.000
time_period_duration	60
reserve_duration	0.50
use_capacity_margin	1
use_online	1
use_ramps	1
use_non_synchronous	1
use_inertia_limit	1
mode_invest	0
mode_dispatch	1
print_duration	0
print_durationRamp	0
print_unit_results	0

1.2 The **nodeGroup** sheet is used to assign system constraints such as capacity margin requirements or Inertial limits to a set of nodes. These constraints will be applied to all member nodes of each group. Here we defined two groups: The first one is named *sync* to specify the inertia limit, capacity margin and non-synchronous share limit. The second one, *reserve1* is used to specify whether to apply the dynamic reserve requirements specified in **te\_reserve\_nodegroup** sheet. For example: the sum of inertia in all nodes in *sync* node group should be higher than 10000 MWs.

nodeGroup	capacity margin (MW)	non synchronous share	inertia limit (MWs)	use ts_reserve	use dynamic reserve	color in results
sync	343	0.80	10000	0	0	
reserve1				1	1	

1.3 The **gridNode** sheet is used to define different grids and the nodes on each grid. As explained in lecture 16, you can define different grids such as gas, electricity mobility etc. each constitute of different nodes in FlexTool. In this case we define only an electricity grid (*elec*) and



represent the whole region with a single node (*nodeA*) to be consistent with the electricity system developed in OSeMOSYS. We assign *nodeA* to both sync and reserve1 groups which means their constraints will be applied to *nodeA*. The total demand, import and capacity margin should also be specified for each node. The capacity margin is considered to be 15% of total demand. Therefore calculated as:  $0.15 * \text{demand} / 8760$ .

grid	node	nodeGroup	nodeGroup2	nodeGroup3	demand (MWh)	import (MWh)	capacity margin (MW)	non synchronous share	use ts_reserve	use dynamic reserve	print results	color in results
elec	nodeA	sync	reserve1		20027794	0	343		1	1	1	

1.4 The **unit\_type** sheet is used to define all the technologies in the system. Since we only have the electricity grid, all the technologies are electricity generation or storage units.

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 (MW s/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
PWRCOA	0.39	0.40	0.34	0.02	0.02	36.0	1.00	1.00	6.00	78	2500			2.00						35	0.10	0.104	0
PWROHC	0.35	0.50	0.30	0.05	0.05	108.0	1.00	1.00	6.00	35	1200			1.00		5.00				25	0.10	0.110	0
PWRNGS001	0.59	0.20	0.54	0.20	0.20	53.0	1.00	1.00	6.00	35	1200			0.50	4.00					30	0.10	0.106	0
PWRNGS002	0.39	0.20	0.34	0.20	0.20	63.0	1.00	1.00	6.00	20	700			0.50	4.00					25	0.10	0.110	0
PWRBIO	0.35	0.40	0.30	0.02	0.02	16.0	1.00	1.00	6.00	75	2500			2.00						30	0.10	0.106	0
PWRHYD	1	0.10	1.00	0.20	0.20		1.00	1.00	6.00	90	3000									50	0.10	0.101	0
PWRGEO	0.35	0.30	0.30	0.02	0.02	12.0	1.00	1.00	6.00	120	4000			1.00						25	0.10	0.110	0
PWRNUC	0.33	0.75	0.28	0.00	0.00	12.0	1.00	1.00	7.00	184	6137			6.00						50	0.10	0.101	0
PWRSOL	1			1.00	1.00		1.00	0.90		12	886									24	0.10	0.111	1
PWRWIND	1			1.00	1.00		1.00	0.90		44	1087									25	0.10	0.110	1

Note that since FlexTool performs a detailed flexibility assessment of the power grid, more detailed data on the operation of different technologies such as their ramp rate, inertial constant and start-up costs etc., are required to define units in FlexTool. Thus not all the data needed to define units can be obtained from OSeMOSYS, and some parameters should be collected from other sources. Here, the columns highlighted in red are the data obtained from OSeMOSYS, and the rest are collected from other sources.

Furthermore, in OSeMOSYS the cost of fuels are considered for primary resources; therefore, there is no separate O&M cost available for conversion technologies. Since the O&M cost is required in FlexTool we calculated them based on the fuel prices (which is the main O&M cost).



Note: Since the model boundaries are different the efficiency of geothermal is considered to be 0.35 instead on 0.8 that is considered in OSeMOSYS.

1.5 The **fuel** sheet is used to define the cost and carbon intensity of different fuels. The data highlighted in red is obtained from OSeMOSYS. In flexTool a cost is also defined for the geo heat which we have added. However, this is optional.

fuel	fuel (price/MWh)	CO2 content (t/MWh)
COA	17.38	0.34
OIL	49.03	0.26
NGS	43.26	0.20
BIO	5.76	0.36
GEO_heat	5.00	0

1.6 The **unitGroup** sheet is used to define unit groups and assign constraints to them. You can group different technologies and specify different limits for them, such as minimum or maximum investment. In this case, although we have defined different groups of technologies, we haven't specified any specific constraints for them.

unitGroup	max invest MW	min invest MW	max invest MWh	min invest MWh	print results	color in results
Fossil					1	
Hydro					1	
Wind					1	
PV					1	
Bio					1	
Geo					1	
NUC					2	



## Step 2: Filling the green sheets

2.1 The **ts\_cf** is used to add the capacity factors for different technologies. Capacity factor is the output of each technology for one MW of the capacity installed. It is usually used for technologies whose output varies over time with respect to weather conditions and other external factors.

	cf_profile	wind_A	PV_A	Hydro_A
<b>Time</b>				
t0000		0.202	0	0.334
t0001		0.228	0	0.334
t0002		0.242	0	0.334
t0003		0.245	0.008	0.334
t0004		0.184	0.14	0.334
t0005		0.267	0.317	0.334
t0006		0.342	0.465	0.334
t0007		0.342	0.566	0.334

Note that for hydropower, we defined the capacity factor instead of inflow data which is usually used in FlexTool to show the change in the hydropower output with variations in the inflow water. This is because in OSeMOSYS, hydro power output is defined with capacity factor and the inflow data was not available. Doing so we leave the **ts\_inflow** sheet empty.

	inflow	Hydro_A
<b>time</b>		
t0000		
t0001		
t0002		
t0003		
t0004		
t0005		
t0006		
t0007		

2.2 The **ts\_energy** sheet is used to add the end-use demand profiles. Here, since we are studying the power grid, we only have the electricity demand profile. However, as discussed previously, you can also add demand for other end-use services such as heat and mobility.

	grid	elec
	node	nodeA
time		
	grid	elec
	node	nodeA
time		
t0000		
t0001		
t0002		
t0003		
t0004		
t0005		
t0006		
t0007		
t0008		

2.3 The **ts\_import** sheet is used to add power import profile. In this case we assume there is no import so we leave this sheet empty.

2.4 The **ts\_reserve\_node** is used to add the reserve requirements at each node at each time step. Here we use a fixed value of 230 MW. The **ts\_reserve\_nodeGroup** is used to define the reserve requirements for a node group and it should be higher than the sum of reserve required for all node members. In this case, since the reserve1 group has only one node member, the reserve required is equal to the reserve at *nodeA*.

	node	nodeA
Time		
t0000		343
t0001		343
t0002		343
t0003		343
t0004		343
t0005		343
t0006		343
t0007		343
t0008		343
t0009		343

	nodeGroup	reserve1
Time		
t0000		343
t0001		343
t0002		343
t0003		343
t0004		343
t0005		343
t0006		343
t0007		343
t0008		343
t0009		343

2.5 The **ts\_unit** is used to add time series for unit characteristics that vary over time for example the conversion efficiency of the heat pump as discussed in Lecture 16. In this case we don't have any characteristics parameter that varies over time therefore we leave this sheet empty.

### Step 3: Filling the yellow sheets

3.1 The **units** sheet is used to define the grid structure (such as installed capacities) and input and output links to the units.

- Add all the units defined in unit\_type (you can choose them from the dropdown menus)
- Assign them to a unit group.
- Add the input fuel or assign a capacity factor to each technology.
- Specify the input grid and nodes if any.
- Specify the output grid. In this case, the output grid for all the technologies is nodeA in the electricity grid.
- Specify the installed capacity at each node. In case of storage units, specify the storage capacity (MWh) as well. All the input data are from OSeMOSYS.
- If there are multiple outputs for example, in the case of combined heat and power, you should specify output2 grid as well.



Add empty row		Choose one input option (none, fuel, cf profile, inflow or input grid+node)					Output #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)	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
Fossil	PWRCOA	COA					elec	nodeA	14														
Fossil	PWROHC	OIL					elec	nodeA	0														
Fossil	PWRNGS001	NGS					elec	nodeA	350														
Fossil	PWRNGS002	NGS					elec	nodeA	0														
Bio	PWRBIO	BIO					elec	nodeA	90														
Hydro	PWRHYD		Hydro_A				elec	nodeA	274														
Geo	PWRGEO	GEO_heat					elec	nodeA	1756														
NUC	PWRNUC						elec	nodeA	0														
PV	PWRSOL		PV_A				elec	nodeA	170								0.10						
Wind	PWRWND		wind_A				elec	nodeA	0								0.10						

Note: For wind and solar units, you can specify how the required reserve should increase as the penetration of these variable renewables increases. In this case, we have specified the reserve increase ratio to 10%, which is the default value used in FlexTool.

3.2 The **nodeNode** sheet is used to specify the transmission links characteristics between different nodes. Since we are using a single node there is no need to specify the transmission links and we leave the sheet empty.

Add empty row															
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		

After adding all the required data, copy the excel file in the input data folder in the flexTool root folder.

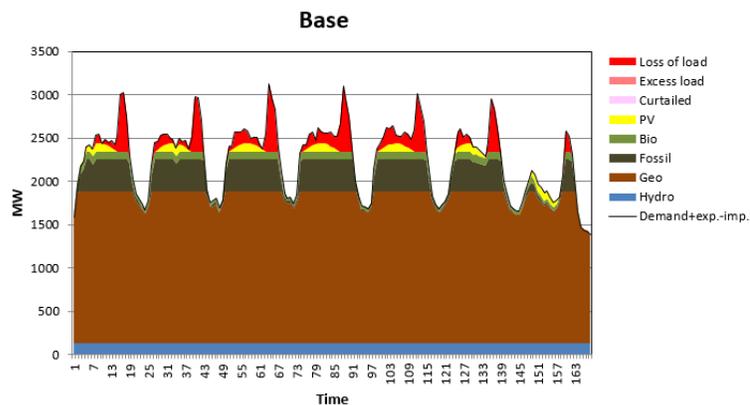
## Activity 2

In the second activity, we want to assess the flexibility of the power system. To do so, add the input data to the active input data, run the Base scenario and wait for the result file.

**Important note:** make sure the macro is activated in the new input file otherwise, you will get an error when running the model.

### Questions:

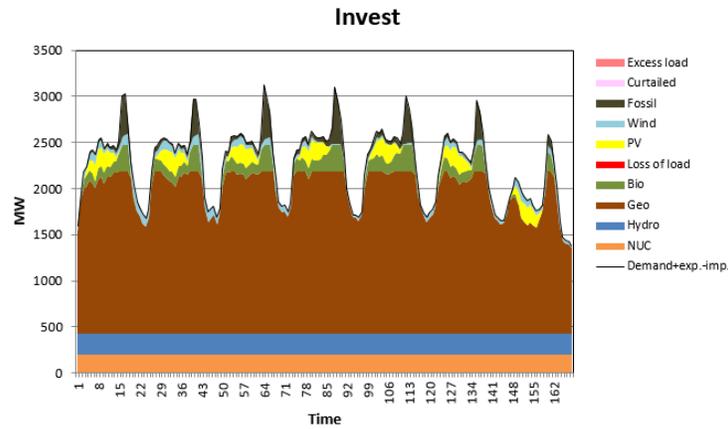
- Is there any flexibility issues in the system?
- What do you think the source of inflexibility is?  
**Hint:** Check the **genUnitGroup\_elec** for the dispatch profile and **units\_elec** sheets for different units' utilization rate.
- Do you think adding more storage units such as battery will reduce the flexibility issues?



It is evident from the dispatch profile that the availability of solar power is already aligned with the power demand, and also all the units are running at almost full capacity (No curtailments). Therefore the main issue seems to be insufficient capacity.

In the next step, we want to run the model in invest mode. Open the input file, and in the **units**, set the maximum investment to 200 MW for all technologies. We are using the same level of investment capacity for all units is to have a fair assessment of different technologies and find

out which technologies will be chosen by the model. Add *invest* to active scenarios and run the model.



### Questions:

- Does the system still has any flexibility issues?
- How did the technology mix changes? Which technologies were installed?

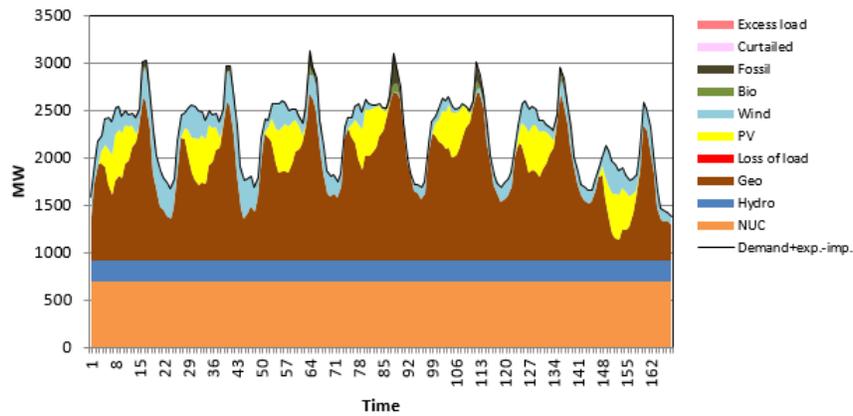
Node	Unit	Base			Invest		
		Capacity (MW)	Generation (MWh)	Utilization (%)	Capacity (MW)	Generation (MWh)	Utilization (%)
	PWRCOA	14	84800.596	69.145952	190.646	164772.24	9.8662531
	PWRNGS001	350	2047364.9	66.776417	550	351299.94	7.2914059
	PWRBIO	90	632234.22	80.192062	290	924613.56	36.396377
	PWRHYD	274	1150384	47.927875	474	1990072.1	47.927675
	PWRGEO	1756	14874265	96.695639	1756	13754466	89.415972
nodeA	PWRSOL	170	260266.78	17.476952			
	PWROHC				200	573.88837	0.032756186
	PWRNGS002				200	26817.03	1.5306524
	PWRNUC				200	1752000	100
	loss of load		978480.01				
	excess load		0				

**Try it :** Increase the level of Maximum investment to 700MW for all technologies and run the model again. You can also do that by adding a sensitivity scenario.

### Questions:

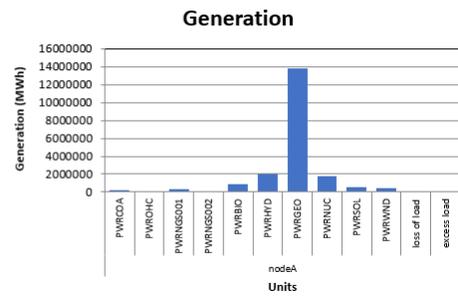
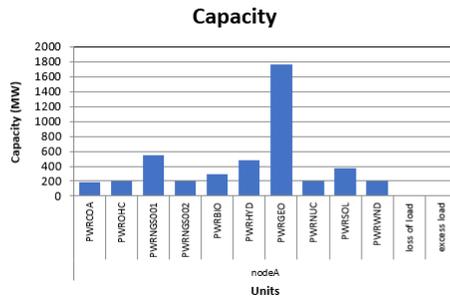
- How does the capacity mix changes by relaxing the maximum investment level?

### Invest

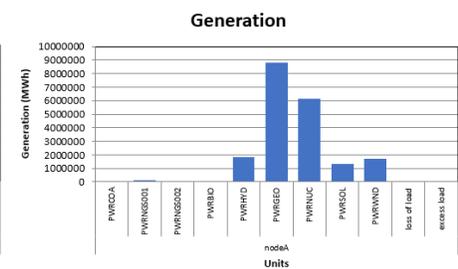
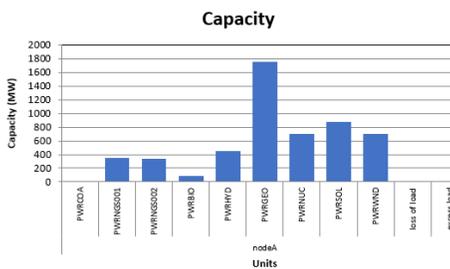


Compare the installed capacities and the generation of different units in both investment cases and check for which technologies the installed capacity was increased?

**Max invest 200 MW**



**Max invest 700 MW**



If increased level of Max investment for different technologies affected the role and value of different technologies. In this case, the Nuclear and Hydro replaces geothermal in supplying the base load and geothermal generators are used to supply intermediate and peak loads.



**Activity:** Try adding other flexibility options such as hydrogen, power to heat or power to EV instead of increasing Max capacity and check how it would affect the system operation and technology mix,