IRENA FlexTool

TRAINING FOR EASTERN EUROPE AND CENTRAL ASIA
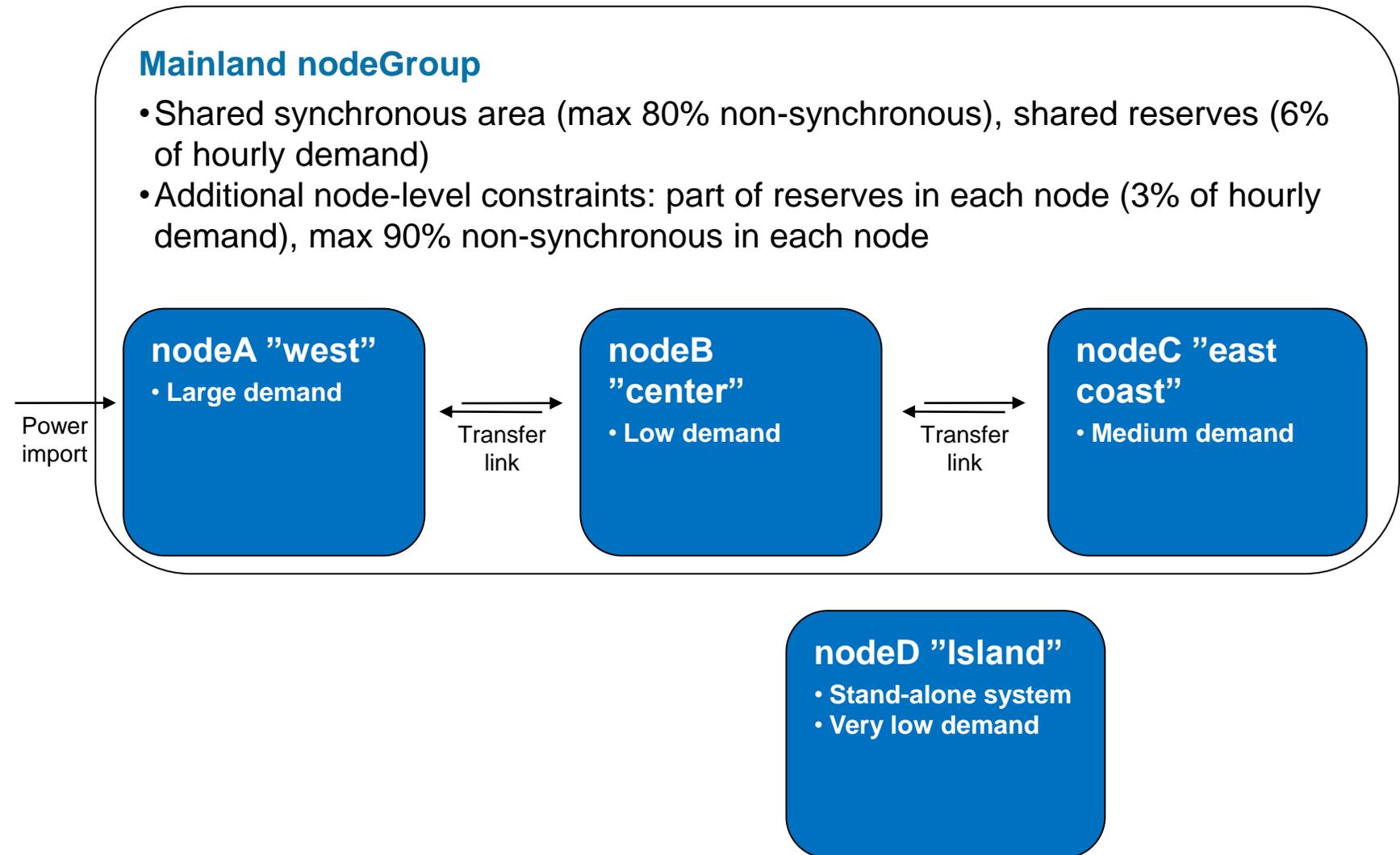
SESSION 4: Running a demo model: how to detect and solve flexibility issues

Introducing demo models for training

Demo model framework

Demo models of an imagined country to demonstrate the most important features of IRENA FlexTool

◦ The basic structure is the same for each demo model

◦ Each demo model is designed to have specific flexibility issues

◦ Training participants are instructed to assess and solve these

Mainland nodeGroup

- Shared synchronous area (max 80% non-synchronous), shared reserves (6% of hourly demand)
- Additional node-level constraints: part of reserves in each node (3% of hourly demand), max 90% non-synchronous in each node

nodeA "west"
• Large demand

Power import

Transfer link

nodeB "center"
• Low demand

Transfer link

nodeC "east coast"
• Medium demand

nodeD "Island"
• Stand-alone system
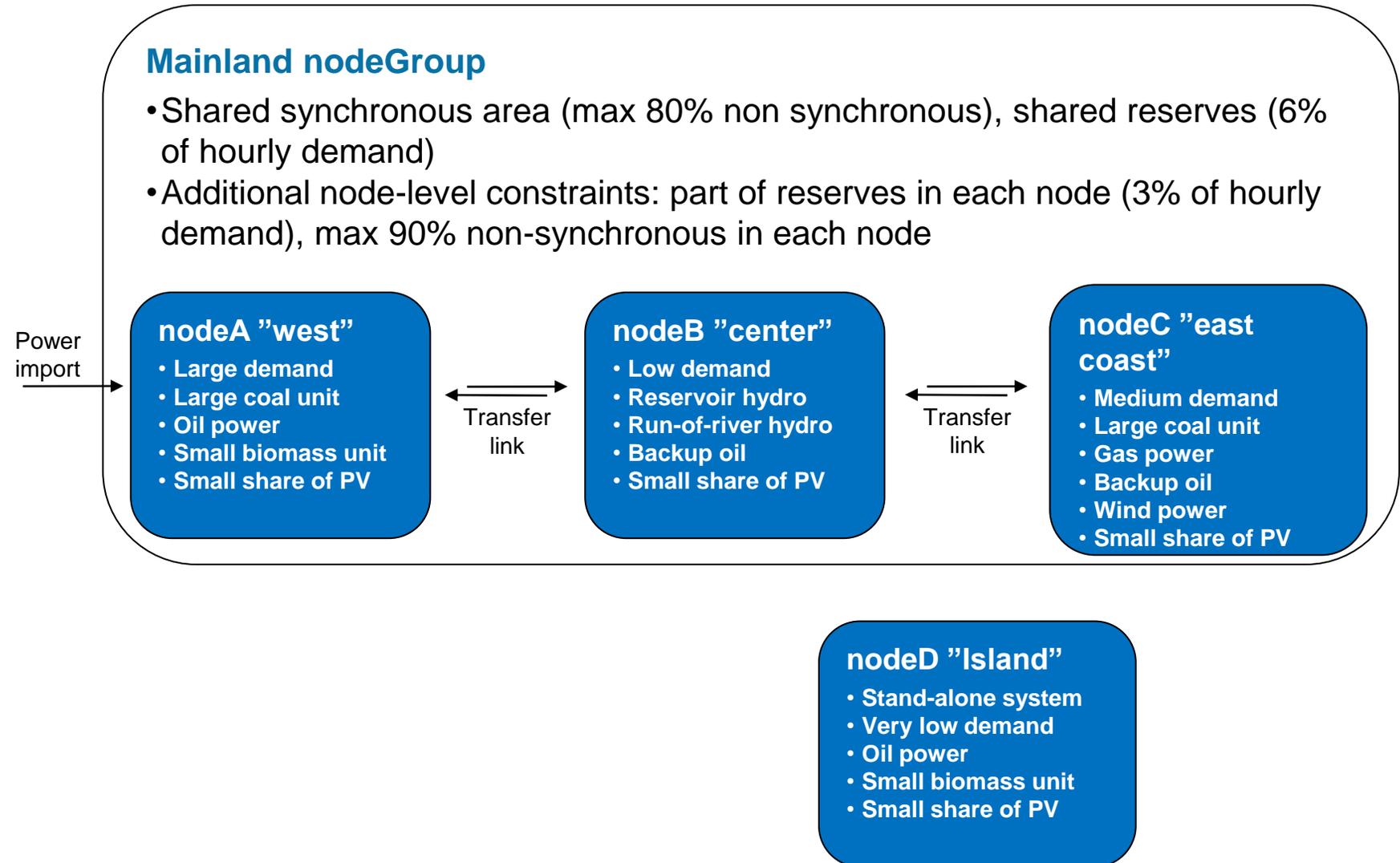• Very low demand

Model solve time

- Increasing **complexity** quickly increases model **solving time**
  - 4 nodes
  - Hydro storages
  - Investment run

- Good flow in training requires very quick solving times
  - Thus, very few hours are modelled (4 week dispatch, 4 day invest)
  - In practice, it is recommended to use shorter time series for testing and longer or full year for actual modelling

- In addition, some time goes to writing the data and results

Number of modelled hours	Dispatch	Invest + Dispatch
24 (1 day)	1 sec	2 sec
72 (3 days)	2 sec	15 sec
168 (1 week)	5 sec	1.5 min
672 (4 weeks)	20 sec	…
…	…	

Running flexibility assessments with demo models – Demo model 1

Demo model 1

Open 'inputData\demoModel-1.xlsm'

◦ Check "**units**" sheet

◦ Model has mostly fossil fuel based generation,

◦ Some hydro power in nodeB, wind power in nodeC, and small shares of PV and biomass in most nodes.

Mainland nodeGroup

- Shared synchronous area (max 80% non synchronous), shared reserves (6% of hourly demand)
- Additional node-level constraints: part of reserves in each node (3% of hourly demand), max 90% non-synchronous in each node

Power import →

nodeA "west"
- Large demand
- Large coal unit
- Oil power
- Small biomass unit
- Small share of PV

Transfer link

nodeB "center"
- Low demand
- Reservoir hydro
- Run-of-river hydro
- Backup oil
- Small share of PV

Transfer link

nodeC "east coast"
- Medium demand
- Large coal unit
- Gas power
- Backup oil
- Wind power
- Small share of PV

nodeD "Island"
- Stand-alone system
- Very low demand
- Oil power
- Small biomass unit
- Small share of PV

Demo model 1

Try running the Base run of the demo model 1

◦ Just testing that it works for everyone

Our initial assessment of the flexibility enablers on the demo model 1 is presented on right

Go through the following slides to see if you agree or will have different conclusions

Flexibility enablers in the demo model 1

Flexibility enablers	High	Medium	Low
Interconnection capacity vs. average demand			🔴
Generator ramping capabilities	🟢		
Matching of demand with VRE generation		🟡	
Hydro inflow stability		🟡	
Strength of internal grid			🔴
Storage vs. annual demand			🔴
Geographical dispersion of VRE generation and demand			🔴
Minimum demand vs. VRE capacity	🟢		

Quick check of flexibility issues

◦ Import results from the Base run of demo model 1.

   ◦ See instructions from day 1 presentation if needed

   ◦ Check **General results** and **Flexibility issues** from **Summary_D**

➢ Notable loss of load, need to find out where and why

➢ Very minor curtailments, not a real issue

➢ No other flexibility issues

Some lines are explained next to the number.

Open result file explanations to see definition for the rest

	A	B
1	Update sheets window	demoModel-1
2		Base
21		
22	General results	elec
23	VRE share (% of annual demand)	8.554
24	Loss of load (% of annual demand)	2.368
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)	
29	Curtailment (% of VRE gen.)	-6.66E-06
30	-> ramp down constrained (% of VRE gen.)	0
31	Peak load (MW)	2101.55
32	Peak net load (MW)	1946.3
33		
34	Flexibility issues	elec
35	Loss of load (max MW)	255.475
36	Excess load (max MW)	0
37	Reserve inadequacy (max MW)	0
38	Insufficient inertia (TWs/a)	0
39	Curtailment (max MW)	0.000137541
40	Curtailment (TWh/a)	-7.48E-08
41	Model leakage (TWh/a)	0
42	Capacity inadequacy (max MW)	0
43	Spill (TWh/a)	0

Loss of load, 1/2

IRENA
FlexTool

Checking total capacity balance to find the reason for loss of load

◦ Possible to do prior to model, from input data or results file

◦ Here checked from the results file

◦ Open results file of Base run

  ◦ **Summary_D** shows peak demand, capacity, and generation (figures at right)

◦ Peak load is less than dispatchable capacity. Peak net load even less. Country level sum is ok, no problems here.

◦ Problems must arise from certain node or nodes

Demo model 1, sum of all nodes

Legend:
- ST_coal
- Engine_gas
- CC_oil
- ST_bio
- Hydro_RES
- Hydro_ROR
- wind
- PV
- ◇ Peak demand
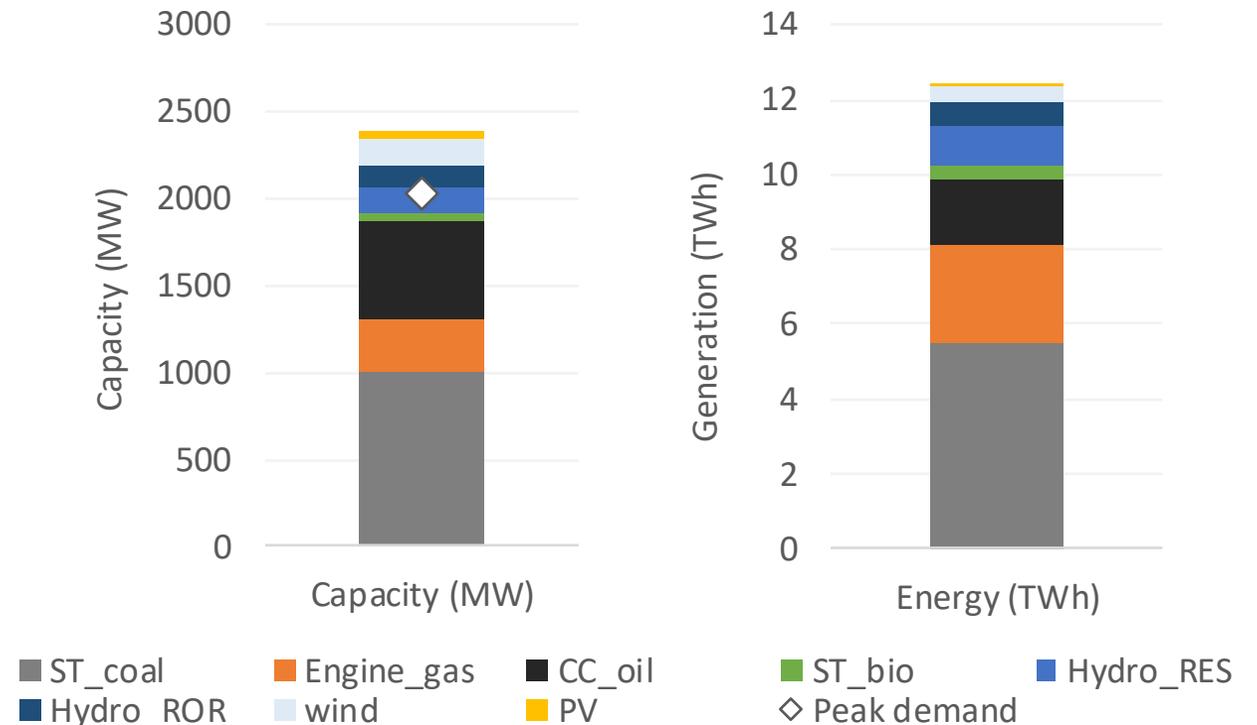
To check node level results

○ Open "**node_plot**" sheet from the results file

  ○ The first figure shows that loss of load is from nodeA

  ○ The second and third figure on the second row show that nodeC transfers electricity to nodeA

○ The conclusion is there would be enough generation capacity (previous slide) but it is not where demand is and/or there is not enough transmission capacity

○ Possible solutions:

  ○ investing to transmission capacity,

  ○ investing to generation capacity,

  ○ investing to storages

○ Need to check benefits and costs of each option

Load shedding
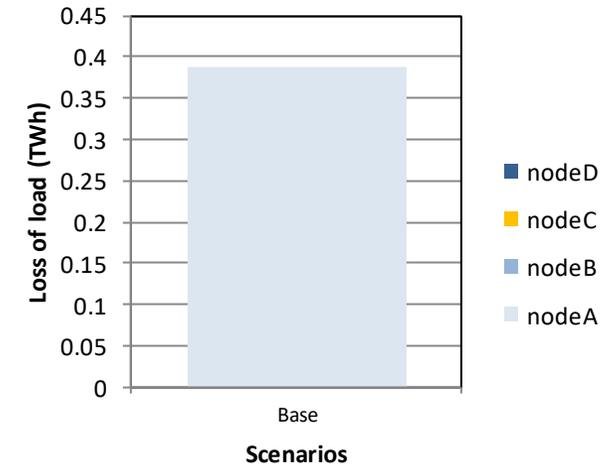
Transfers to the node
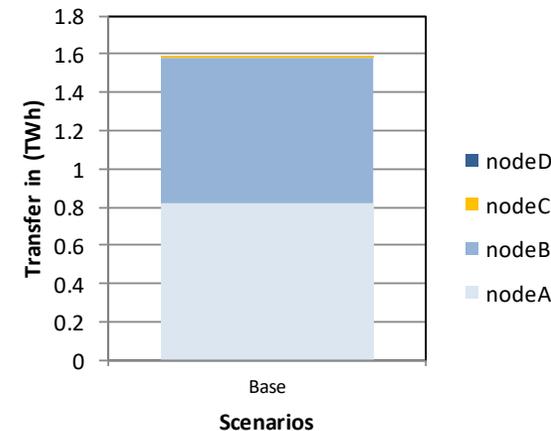
Transfers out of the node
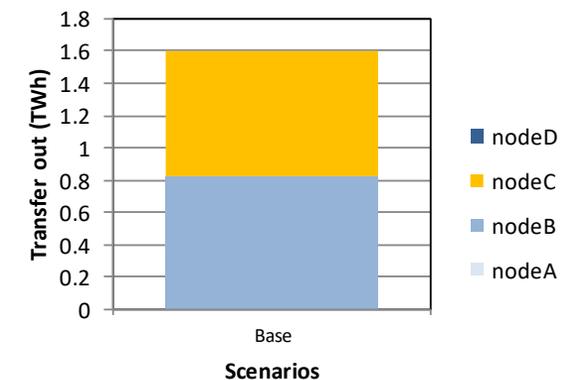
◦ We want to study how the **loss of load issue** could be fixed

◦ We want to study **three different measures**:

  ◦ Investing in transmission capacity

  ◦ Investing in generation capacity

  ◦ Investing in storages

◦ In addition, we want to **compare these options** and see if they would better alone or together

  ◦ Fourth investment scenario: investing to all three groups

Open flexTool.xlsm

a) From 'settings and filters' sheet, set max number of parallel calculation = 3 (or number of cores -1)

b) Select demoModel1 and 5 scenarios as in figure

c) Click '**write time series and run model**'

d) Wait until result file opens
   ◦ Sometimes the result file fails to open, and does not show numbers. In this case, close the file, go to folder **results**, and open the most recent file.

a

b

c

d

In results file

a) Open **summary_D** sheet

b) Check **General results** and **Flexibility issues** tables

- Transfer invests removed loss of load

- Generation capacity investments removed loss of load

- Storage investments helped with loss of load, but did not fully solve it

- All scenarios still have tiny amount of curtailments, but the values are very small and user should not be concerned about those

	A	B	C	D	E	F
1	Update sheets window	demoModel-1	demoModel-1	demoModel-1	demoModel-1	demoModel-1
2		Base	demo1_invest_transCap	demo1_invest_genCap	demo1_invest_storages	demo1_invest_all
23	VRE share (% of annual demand)	8.554	8.554	13.45	8.554	13.68
24	Loss of load (% of annual demand)	2.368	0	0.8025	1.449	0
25	-> ramp up constrained (% of annual demand)	0	0	0	0	0
26	Excess load (% of annual demand)	0	0	0	0	0
27	Insufficient reserves (% of reserve demand)	0	0	0	0	0
28	Insufficient inertia (% of inertia demand)					
29	Curtailment (% of VRE gen.)	-6.66E-06	-6.66E-06	-9.25E-06	-6.66E-06	0.3904
30	-> ramp down constrained (% of VRE gen.)	0	3.07E-08	2.32E-09	0	0
31	Peak load (MW)	2101.55	2101.55	2101.55	2101.55	2101.55
32	Peak net load (MW)	1946.3	1946.3	1934.92	1946.3	1933.66
33						
34	Flexibility issues	elec	elec	elec	elec	elec
35	Loss of load (max MW)	255.475	0	243.126	221.823	0
36	Excess load (max MW)	0	0	0	0	0
37	Reserve inadequacy (max MW)	0	0	0	0	0
38	Insufficient inertia (TWs/a)	0	0	0	0	0
39	Curtailment (max MW)	0.000137541	0.000137541	0.000476468	0.000137541	27.855
40	Curtailment (TWh/a)	-7.48E-08	-7.48E-08	-1.63E-07	-7.48E-08	0.00701932
41	Model leakage (TWh/a)	0	0	0	0	0
42	Capacity inadequacy (max MW)	0	0	0	0	0
43	Spill (TWh/a)	0	0	0	0	0

In results file

a) Open **summary_D** sheet

b) Check **costs** table

- Storage investment scenario has lower loss of load costs than base, but still significant
- Other scenarios have zero costs from loss of load
- All investment scenarios have lower total sum than base
- Which has the lowest total costs?

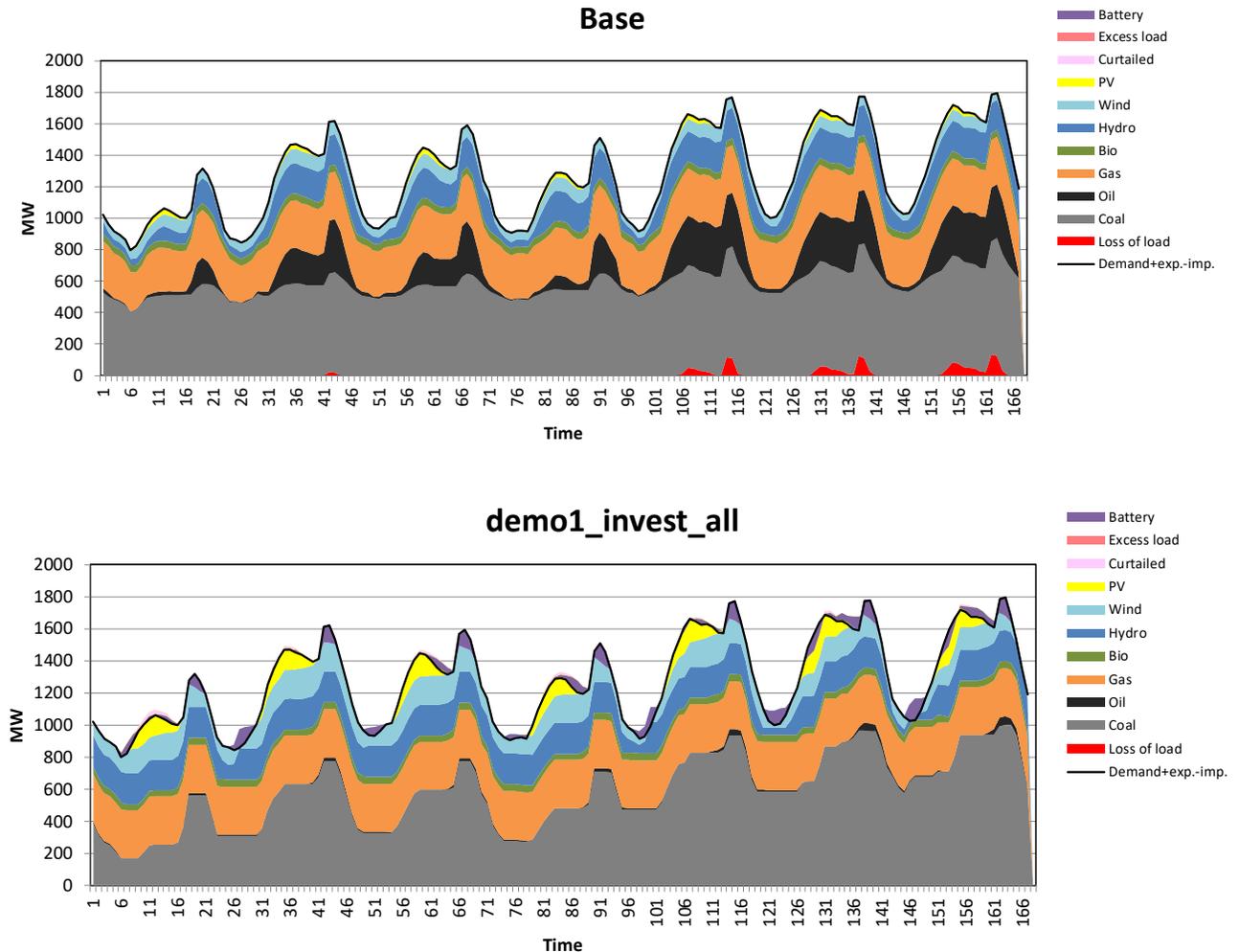|	A	B	C	D	E	F
1	Update sheets window	demoModel-1	demoModel-1	demoModel-1	demoModel-1	demoModel-1
2		Base	demo1_invest_transCap	demo1_invest_genCap	demo1_invest_storages	demo1_invest_all
57						
58	Costs	elec	elec	elec	elec	elec
59	Cost operations (M CUR)	609.876	574.333	565.147	617.628	502.201
60	Cost investments (M CUR)	0	4.86935	29.7572	1.85097	37.8718
61	Fixed annual costs (M CUR)	101.251	101.251	106.251	105.212	112.512
62	Cost loss of load (M CUR)	3110.96	0	1054.49	1904.56	0
63	Cost excess load (M CUR)	0	0	0	0	0
64	Cost curtailment (M CUR)	-1.50E-06	-1.50E-06	-3.27E-06	-1.50E-06	0.140386
65	Cost of insufficient reserves (M CUR)	0	0	0	0	0
66	Cost of insufficient inertia (M CUR)	0	0	0	0	0
67	Cost of insufficient capacity (M CUR)	0	0	0	0	0

In results file

a) Open **summary_D** sheet

b) Check capacity investments from **unit type capacity (MW)** table

c) Check tranmission investments from **transfer Capacity (MW)** table

◦ Investments are highlighted at figures on the right

◦ First three scenarios invest into only one of the technology baskets (transmissions, capacity, storages) as defined

◦ The fourth one was able to invest to technologies from each basket and decided to do that

◦ Combination solution did not invest to additional coal or oil capacity, but chose additional gas, biomass, VRE, storages, and transmission

	A	B	C	D	E	F
1	Update sheets window	demoModel-1	demoModel-1	demoModel-1	demoModel-1	demoModel-1
2		Base	demo1_invest_transCap	demo1_invest_genCap	demo1_invest_storages	demo1_invest_all
80	Unit type	Capacity (MW)	Capacity (MW)	Capacity (MW)	Capacity (MW)	Capacity (MW)
81	ST_coal	1000	1000	1000	1000	1000
82	Engine_gas	300	300	300	300	300
83	CC_oil	620	620	620	620	620
84	ST_bio	45	45	45	45	45
85	Hydro_RES	150	150	150	150	150
86	Hydro_ROR	120	120	120	120	120
87	wind	150.02	150.02	300.02	150.02	300.02
88	PV	60	60	260	60	260
89	battery	0.04	0.04	0.04	198.082	313.077

	A	B	C	D	E	F
1	Update sheets window	demoModel-1	demoModel-1	demoModel-1	demoModel-1	demoModel-1
2		Base	demo1_invest_transCap	demo1_invest_genCap	demo1_invest_storages	demo1_invest_all
111						
112	Transfer	Capacity (MW)	Capacity (MW)	Capacity (MW)	Capacity (MW)	Capacity (MW)
113	nodeA - nodeB	150	439.925	150	150	455.759
114	nodeB - nodeA	150	439.925	150	150	455.759
115	nodeB - nodeC	100	405.766	100	100	429.014
116	nodeC - nodeB	100	405.766	100	100	429.014

Comparing different investment options, 6/9

In results file

a) Open **genUnitGroup_elec_plot** sheet

- Check how the model dispatched the units

- Figures on the right show high demand week (4th week) in base run and invest_all run

- You can change the week from a scroll bar at the top

- Notice that demand peak is after the sunset, but PV is still profitable investment because it allows lower oil consumption

- With PV, the model runs oil capacity to provide the peak load when needed

- On the right, low and high demand weeks from invest_all scenario

In results file

a) Open **units_invest_plot** sheet

  ◦ First figure shows invested capacities per node

  ◦ First figure on the second row shows the same figures for storage capacity

b) Open **transfers_invest_plot** sheet

  ◦ Figures show invested transfer capacity and shadow value of additional investments
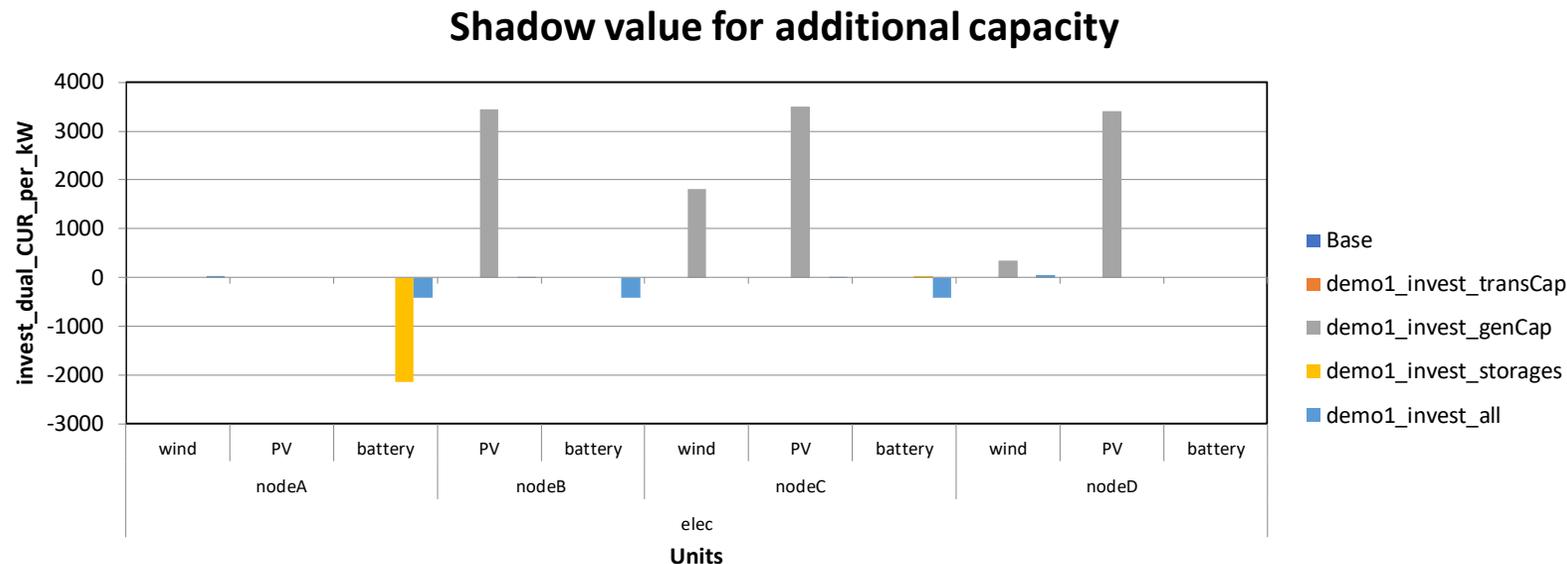
IRENA
FlexTool

In results file

a) Open **units_invest_plot** sheet

- Shadow value is a model parameter that tells if additional investment on that technology would reduce total costs or not

- If some technology has positive shadow value, investment would increase the overall costs (*i.e.,* not profitable)

- If some technology has negative shadow value, additional investments would decrease the total costs, but some constraint did not allow additional investments

- In demo model 1, the maximum allowed investments were predefined and storage scenario would have been cheaper if model could have invested to larger storages.
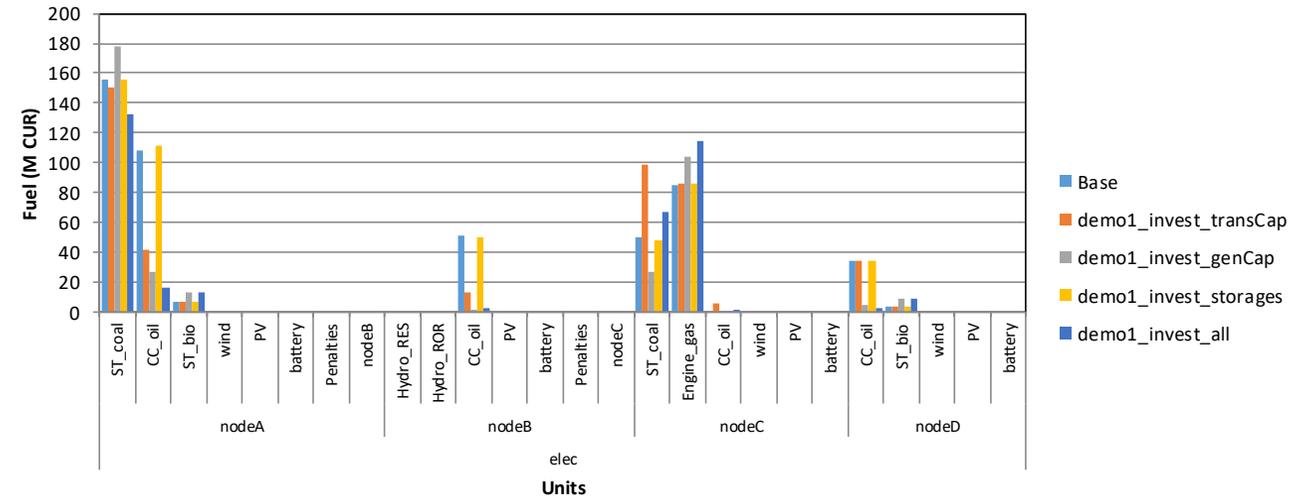

Shadow value for additional capacity
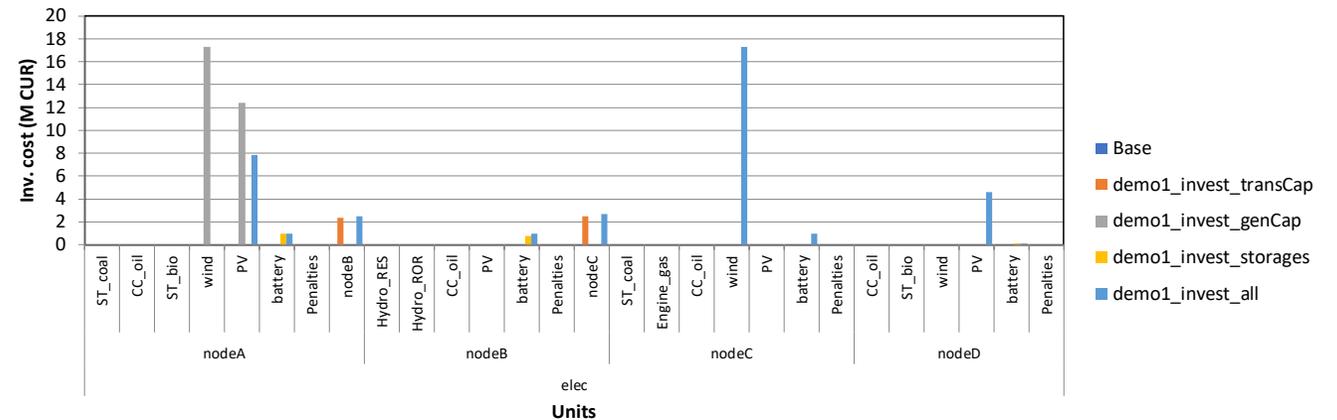
In results file

a) Open **costs_plot** sheet

  ◦ FlexTool calculates a large range of different costs and shows detailed results

  ◦ On right is a breakdown of fuel costs and (annualised) investment costs

  ◦ Results file shows also many other categories

Selecting the modelled days for demoModel 1

◦ Selected representative time series were based on
  - Net load (min and max)
  - Inflow (min and max)

◦ **Open file input/demoModel-1-select-weeks.xlsx**
  ◦ The file is very slow to use,
  ◦ Closing additional excel files speeds up things a bit

◦ Selecting 4 weeks for dispatch and 4 days for invest
  ◦ 1 week/day with max net load
  ◦ 1 week/day with min net load
  ◦ 1 week/day with max inflow
  ◦ 1 week/day with min inflow

◦ Quality check by comparing the duration curves of the full year to selected time series (figures at right)
  ◦ 4 days is too small sample, but we will still use it to get faster model run times

Net load duration curve

Inflow duration curve

Acknowledgments and Additional Info
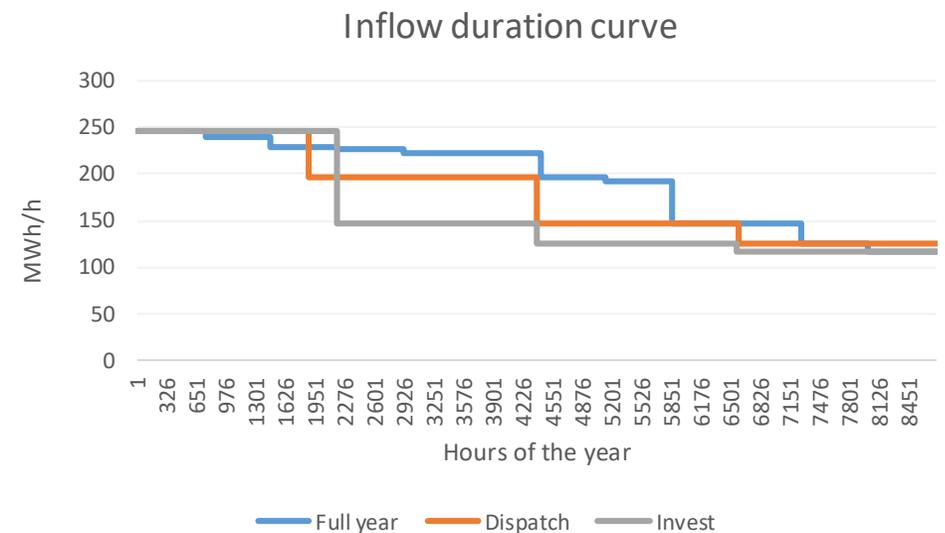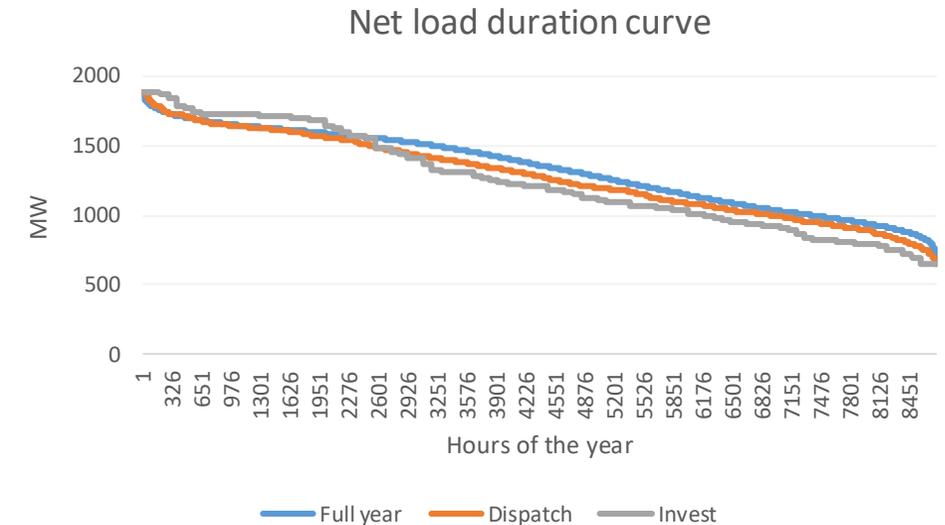
- **VTT Technical Research Centre of Finland**
  - Juha Kiviluoma – Main developer of the tool
  - Tomi Lindroos – Tool testing and analysis of case studies
  - Simo Rissanen – Tool code developer

- **International Renewable Energy Agency**
  - IRENA Innovation and Technology Center (IITC)
  - Work led by the Power Sector Transformation Team under the guidance of Emanuele Taibi

- **Contact information**
  - Support on the tool: Flextool@irena.org

www.irena.org

www.twitter.com/irena

www.facebook.com/irena.org

www.instagram.com/irenaimages

www.flickr.com/photos/irenaimages

www.youtube.com/user/irenaorg