Introducing Ancillary Services Markets in TIMES

ETSAP Webinar, 15th October 2021
What happens in the grid when there is a power outage?

A photo of an Alpine Helicopter test on a wind farm in the winter of 2013-2014 in the Uljabuouda mountains in Arjeplog, Sweden. Foto: Alpine Helicopter

https://www.nyteknik.se/energi/helikopter-stralen-ar-nya-vapnet-mot-isen-6395827
Aim of the extension

Brief introduction to Ancillary Services Markets

Key features of the TIMES extension of modelling Ancillary Services Markets

Working example
## Agenda

1. Aim of the extension
2. Brief introduction to Ancillary Services Markets
3. Key features of the TIMES extension of modelling Ancillary Services Markets
4. Working example
Aim of the extension

- Energy system reliability and security
- Renewable integration costs
- Market-based mechanism for flexibility
- Remuneration for new flexibility
The extension can be combined with...

- Dispatching features extension
- Grid extension
- Residual Load Curve extension

... to improve TIMES investment and operational decisions
Agenda

1. Aim of the extension
2. Brief introduction to Ancillary Services Markets
3. Key features of the TIMES extension of modelling Ancillary Services Markets
4. Working example
The electricity system balances the supply and demand of:
- energy
- operational reserve capacity for short-term imbalances

Short-term imbalances can occur on the:
- Network load side
- Production side

The operating reserve is the generating capacity available within a short time interval to balance the energy supply and demand.
Types of operating reserve capacity

- Frequency Containment Reserve (FCR)
  - activated automatically in seconds

- Automatic Frequency Restoration Reserve (FRR)
  - activated after FCR to relieve the units provided it
  - automatic (aFCR)
  - manual (mFCR)

- Replacement reserve (RR):
  - activated after RR to support or relief the FRR
  - not always implemented

The reserve can be positive (upward) or negative (downward)

Other names:
Primary control reserve
Secondary control reserve
Tertiary control reserve
In the case of a power plant failure

Source: Swissgrid, 2010
Calculating the demand for reserve requirements

- Differs between countries and reserve types
- Mix of deterministic and probabilistic approaches

Real world example based on the Belgian System Operator

Source: ELIA, 2017
Deterministic component of the demand calculation:

- Equal to the loss of the largest single grid element
- Both for negative and positive reserve
- Also used when the reserve is determined outside the «control area»
Example: FCR sizing in ENTSO-E Control Area

- ENTSO-E uses N-2 criterion for FCR dimensioning
- 3000 MW are considered as a reference incident
- Allocated to countries reflecting their weight

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<th>Country</th>
<th>MW</th>
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<td>ME</td>
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Probabilistic component of the demand calculation:

Can be based on:

- Historical time series of system imbalances (SI)
- Forecast errors

It is represented as:

- Probability density function (pdf)
- Total contracted reserve covers 99% of the pdf

The different types of reserve are provided independently.
The provision of reserve is constraint by:
- Minimum stable operating level
- Ramping rates for energy production
- Ramping rates for reserve provision

A storage is contracted for reserve power $P$ for time $t_2-t_1$
It is first charged to $P$ for time $t_1$, to increase stored energy
It retains stored energy level for time $t_2-t_1$ to provide reserve of power $P$ if needed

Planning Reserve Margin:
• Peak constraint
• Long-term forecast of demand
• % of the median peak load
• Ensures reliability when accounting inherently uncertainty factors

Ancillary services markets:
• Short-term forecast of demand
• “Quick-fixes” of system imbalances

1-in-2 peak: 50% probability that forecast peak will be less than actual peak load, and 50% probability that forecast peak will be greater than actual peak load

Aim of the extension

Brief introduction to Ancillary Services Markets

Key features of the TIMES extension of modelling Ancillary Services Markets
  3.1 Endogenous demand
  3.2 Endogenous supply

Working example
Main assumptions (1/2)

• Modelling the **provision** and not the activation of reserve

• A perfect competitive market

• Each reserve is a TIMES commodity

• No consumption for reserve provision

• Price of reserve from the EQ_COMBALM

• Mark ups and subsidies possible via FLO_COST and FLO_SUB
Main assumptions (2/2)

- Cross-border traded supported via normal trade processes
- UC mechanisms of TIMES supported for reserve commodities: UC_COMNET, UC_FLO(ANNUAL)
- Flexibility in sizing of reserve according to the timeslice tree
- Not all types of reserves need to be modelled
  – as long as their activation hierarchy is respected
1. Aim of the extension
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   3.1 Endogenous demand
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How to define operational reserve commodities

<table>
<thead>
<tr>
<th>VEDA Parameter</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>BS_RTYPE (r,b)</td>
<td>Type of reserve b in region r</td>
</tr>
<tr>
<td>± 1</td>
<td>FCR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td>± 2</td>
<td>aFRR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td>± 3</td>
<td>mFRR-type of reserve (positive or negative)</td>
</tr>
<tr>
<td>± 4</td>
<td>RR-type of reserve (positive or negative)</td>
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</tbody>
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<tr>
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<th>Attribute</th>
<th>Cset_CN</th>
<th>Reg</th>
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<tr>
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<td>-1</td>
</tr>
<tr>
<td></td>
<td>BS_RTYPE</td>
<td>aFRR+</td>
<td>2</td>
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<tr>
<td></td>
<td>BS_RTYPE</td>
<td>aFRR-</td>
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<tr>
<td></td>
<td>BS_RTYPE</td>
<td>mFRR+</td>
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</tr>
<tr>
<td></td>
<td>BS_RTYPE</td>
<td>mFRR-</td>
<td>-3</td>
</tr>
</tbody>
</table>
For each reserve type:

- **Deterministic Component** (e.g. loss of largest grid element)
  - **Exogenous**
  - **Endogenous**

- **Probabilistic component** (e.g. forecast errors)
  - **Exogenous**
  - **Endogenous**

- **Exogenous**
  - Specified by the user as a constant amount
  - Calculated by TIMES from a set of processes
  - Historical forecast errors
  - Dynamically adjusted forecast errors

- Combinations of deterministic and probabilistic components for determining the demand also possible:
  - Max of the two, weighted sum of the two, difference of the two
Calculating the deterministic component of demand

The deterministic component can be:
• Exogenously defined, or
• Endogenously calculated by TIMES, or
• Weighted sum of exogenous + endogenous

### VEDA Parameter

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</thead>
<tbody>
<tr>
<td>BS_DEMDET</td>
<td>Parameter for defining deterministic reserve demand</td>
</tr>
<tr>
<td>dpar=EXOGEN</td>
<td>Reserve b is exogenous</td>
</tr>
<tr>
<td>dpar=WMAXSI</td>
<td>weight of contribution of largest grid element (e..g power plant)</td>
</tr>
<tr>
<td>BS_CAPACT(r)</td>
<td>Conversion factor of reserves from capacity to commodity flow units</td>
</tr>
</tbody>
</table>

\[
VAR_{BSD_{r,j,c,s}} \geq \text{dexog}_{deter}^r \cdot bc_r + \text{deter}^r \cdot ctc_{r,v,j,p} \cdot VAR_{NCAP_{r,v,p}} \cdot \sum_{v=t_{s,r,p}, t \in PRC_{TS(r,p,s)}} \left( af_{r,v,j,p,s}^\text{max} \cdot rs_{r,s,s} \right), \forall r,t,s,c \in A, p \in SI
\]

- WMAXSI defines processes that participate in this calculation
- bc(r) is the max activity to capacity factor across all processes (BS_CAPACT parameter in VEDA)
- If the process timeslice is different than the timeslice of reserve the af_max is adjusted to the average
Example of the deterministic component of the demand

$$VAR_{BSD_{\text{deterministic}}} \geq d_{x,y,z} \cdot c_{x,y,z} \cdot c_{t,y,f,p} \cdot VAR_{NCAP_{r,p,v}} \cdot \sum_{V \in PRC_{TS}(r,p,t)} (a_{f,y,z,p,s} \cdot r_{f,y,z,s}) \quad \forall r, t, s, c \in A, p \in SI$$

The equation is repeated for each process mapped to SI via the GR_GENMAP.

The reserved word SI is used to identify the processes regarded as largest grid element.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Cset_CN</th>
<th>Pset_PN</th>
<th>Other_Indexes</th>
<th>Year</th>
<th>Reg</th>
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<td>GR_GENMAP</td>
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<td>BS_DEMDET</td>
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<td>EXOGEN</td>
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<td>BS_DEMDET</td>
<td>FCR+</td>
<td>WMAXSI</td>
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<td>2020</td>
<td>10%</td>
</tr>
<tr>
<td>BS_DEMDET</td>
<td>FCR-</td>
<td>WMAXSI</td>
<td></td>
<td>2020</td>
<td>10%</td>
</tr>
</tbody>
</table>
Based on user-defined forecast errors, e.g. wind, solar production
The forecast errors are independent random variables
They follow the standard normal distribution

\[ \text{VAR}_{BSD^\text{prob}} = 3 \cdot \sqrt{\sum_k (\sigma_{r,t,c,ts,k}^2 \cdot \text{VAR}_{RLD}^{2})} \]

\[ \text{VAR}_{BSD^\text{prob}} \geq \delta_{r,t,c,s} \cdot 3 \cdot \sum_k (\sigma_{r,t,c,k,s} \cdot \text{VAR}_{RLD}) \]

Scaling factor  Forecast error  System imbalance load
Example of defining the probabilistic component

\[
\text{VAR}_{-BSD}^{\text{prob}}_{r,t,b,k,s} \geq \delta_{r,t,c,s} \cdot 3 \cdot \sum_{k} \left( \sigma_{r,t,c,k,s} \cdot \text{VAR}_{-RLD}^{\text{prob}}_{r,t,b,k,s} \right)
\]

<table>
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<tr>
<th>VEDA Parameter</th>
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<tbody>
<tr>
<td>BS_SIGMA(r, t, b, k, s)</td>
<td>Standard deviation of the forecast error regarding the variation k for the demand for reserve b.</td>
</tr>
<tr>
<td>BS_DELTA (r, t, b, s)</td>
<td>Calibration parameter for probabilistic reserve demand for reserve b, in region r, year t and timeslice s.</td>
</tr>
</tbody>
</table>

- The system imbalances DEMSI, SOLSI, WINSI are user defined, via the BS_SIGMA parameter
- The names DEMSI, SOLSI, WINSI are not fixed and can be altered by the user
Dependencies between the reserve types

- The probabilistic component of demands has dependencies.

\[
\lambda = \frac{aFRR}{FRR} = \frac{\mu + \sigma \cdot \Phi^{-1}(0.85)}{\mu + \sigma \cdot \Phi^{-1}(0.95)} = \frac{\mu + 1.036}{\mu + 1.645} \in (0,1)
\]

- A dependency parameter can be defined as follows:
  - \( \mu \) is the mean of the FRR distribution
  - \( \sigma \) is the standard deviation of the FRR distribution
  - \( \Phi^{-1} \) is the inverse normal distribution

\[
\begin{align*}
\text{aFRR} & : 85\% \text{ quantile} \\
\text{mFRR} & : 95\% \text{ quantile} \\
\text{total FRR} & : 95\% \text{ quantile}
\end{align*}
\]

Source: Brijs et al., 2016
## VEDA Parameter Description

<table>
<thead>
<tr>
<th>VEDA Parameter</th>
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<tbody>
<tr>
<td>BS_LAMBDA(r, t, b)</td>
<td>Dependence factor (fudge factor) used in the calculations of the reserve requirements for reserve b in region r, year y. <strong>If not defined, then the demand for reserve b cannot be calculated.</strong></td>
</tr>
</tbody>
</table>

### Positive Reserve (aFRR+)
- **BS_LAMBDA aFRR+**
  - Year: 2020
  - Reg: 0.8
  - Positive reserve: aFRR is 80% of the total FRR

### Negative Reserve (aFRR-)
- **BS_LAMBDA aFRR-**
  - Year: 2020
  - Reg: 0.2
  - Negative reserve: aFRR is 70% of the total FRR

### FCR Reserve
- **BS_LAMBDA FCR+**
  - Year: 2020
  - Reg: 1.0
  - There is only one type of FCR

- **BS_LAMBDA FCR-**
  - Year: 2020
  - Reg: 1.0
Calculating the total demand

For each reserve type:

- **Demand for reserve**
  - Deterministic Component (e.g. loss of largest grid element)
  - Probabilistic component (e.g. forecast errors)

Possible combinations controlled by the user

<table>
<thead>
<tr>
<th>VEDA Parameter</th>
<th>Description</th>
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</thead>
<tbody>
<tr>
<td>BS_OMEGA ((r,t,b,s))</td>
<td>The demand for reserve (b) in region (r), year (t) and timeslice (s)</td>
</tr>
<tr>
<td>1</td>
<td>Maximum of deterministic and probabilistic component</td>
</tr>
<tr>
<td>2</td>
<td>Weighted sum of deterministic and probabilistic component</td>
</tr>
<tr>
<td>3</td>
<td>Absolute difference between deterministic and probabilistic component</td>
</tr>
<tr>
<td>BS_DETWT ((r,t,b))</td>
<td>Weight of the deterministic component in the total reserve demand, when the weighted sum is used</td>
</tr>
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</table>
Example: calculating the total demand of reserve

<table>
<thead>
<tr>
<th>Attribute</th>
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<tr>
<td>BS_DETWT</td>
<td>FCR-</td>
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<td>1</td>
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Demand for FCR+, FCR- is exogenously given

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<th>Reg</th>
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<tr>
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Demand for aFRR is endogenous equals to the weighted sum of the probabilistic and deterministic component

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<tr>
<td>BS_OMEGA</td>
<td>aFRR-</td>
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Demand for mFRR is endogenous equals to max of the probabilistic and deterministic component

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</tr>
<tr>
<td>BS_OMEGA</td>
<td>RR-</td>
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</table>

Demand for RR is endogenous equals to the difference of the probabilistic and deterministic component
Commodity balance equation for reserves

- The reserve commodities (and their demand) can be defined in any level of the timeslice tree
- LO (default), FX and N are also applied to reserves
- LO and FX : market balance at the commodity timeslice only
- N : market balance at finest timeslice such that:
  - the demands on the timeslice below the commodity timeslice are all the same and equal to the maximum imbalance
Aim of the extension

Brief introduction to Ancillary Services Markets

Key features of the TIMES extension of modelling Ancillary Services Markets

3.1 Endogenous demand

3.2 Endogenous supply

Working example
Assumptions

• Supply processes, storages and demand processes can provide reserve

• When the capacity of storage expressed as power, e.g. NCAP_AFC is used
  – storage is considered to be a supply process

• When the capacity of storage expressed as energy
  – charging times are accounted for
Reserve provision from supply processes

Additional parameters related to the reserve provision:

<table>
<thead>
<tr>
<th>VEDA Parameter</th>
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</thead>
<tbody>
<tr>
<td>BS_RMAX(r, t, p, b, s)</td>
<td>Maximum contribution of process p, vintage v, in timeslice s for the provision of reserve b. Required for enabling reserve provision.</td>
</tr>
<tr>
<td>BS_BNDPRS(r,t,p,b,s,bd)</td>
<td>Absolute bound on the reserve provision b from process p (bd=UP/LO/FX)</td>
</tr>
</tbody>
</table>

BS_RMAX considers the **ramping rate** and the **duration** of reserve provision

*Example:*

*A coal process has hourly ramping rate 30%, and provides aFRR reserve for 7.5 min:*

\[
BS_{RMAX} = \frac{0.3}{60} \times 7.5 = 0.0375
\]

Each reserve type has its own duration:

- *E.g., FCR 0.5 min, aFRR 7.5min, mFRR 15 min*
- **BS_RMAX** is higher for the slower reserves
Required dispatching parameters for supply processes

- To correctly enable the reserve provision equations:

<table>
<thead>
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<th>VEDA Parameter</th>
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</thead>
<tbody>
<tr>
<td>ACT_MINLD (r,t,p)</td>
<td>Minimum stable operating level of process p, in year t</td>
</tr>
<tr>
<td>ACT_UPS (r,t,p,s,bd)</td>
<td>Maximum ramping rate as fraction of capacity per hour</td>
</tr>
<tr>
<td></td>
<td>bd=LO : ramping down</td>
</tr>
<tr>
<td></td>
<td>bd=UP: ramping up</td>
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</tbody>
</table>
Reserve provision from demand processes

- The provision controlled with BS_RMAX and BS_BNDPRS
- Demand processes provide negative reserve
- No ramping and minimum stable operating level
Reserve provision from storages (only when storage levels bounded by capacity)

<table>
<thead>
<tr>
<th>VEDA Parameter</th>
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<tbody>
<tr>
<td>BS_STIME(r,p,b, bd)</td>
<td>Defines the times (in hours) for reserve provision from storage process p</td>
</tr>
<tr>
<td>bd=LO</td>
<td>Time required for a storage process to ramp up</td>
</tr>
<tr>
<td>bd=UP</td>
<td>Duration of the provision of reserve from storage process</td>
</tr>
</tbody>
</table>

Brijs et al., 2016
Reserve provision: 7.5 minutes

- EGTCC: 50% ramping rate
- EHYD-PUM: 60% ramping rate
- EBATSTG: 1.5h to (dis)charge and needs to provide reserve for an additional 0.13h
Maintenance and outages of power plants

- Current: derating the nameplate capacity by using NCAP_AF<1
- New: Capture the discrete character of maintenance by specifying the maintenance period
  - TIMES can also optimise when to enter a process into maintenance

<table>
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<tbody>
<tr>
<td>BS_MAINT(r,v,p,s)</td>
<td>Endogenous maintenance scheduling</td>
</tr>
<tr>
<td></td>
<td>Defines the minimum continuous maintenance time of process p in <strong>hours</strong></td>
</tr>
<tr>
<td></td>
<td>$s$ can be a process timeslice, or more usefully above it, to allow for optimizing the maintenance period</td>
</tr>
<tr>
<td></td>
<td>If defined on DAYNITE or WEEKLY level, requires that start-ups are explicitly enabled on that level (using ACT_CSTUP/ACT_CSTSD).</td>
</tr>
<tr>
<td></td>
<td>If BS_MAINT&gt;24h it applies to a whole SEASON</td>
</tr>
</tbody>
</table>
**Maximum number of cycles for storages (storage degradation approximation)**

<table>
<thead>
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</tr>
</thead>
<tbody>
<tr>
<td>STG_MAXCYC(r,t,p)</td>
<td>Maximum number of cycles for a storage process p</td>
</tr>
</tbody>
</table>

- Example of application: batteries in electric cars
  - NCAP_PASTI = 1 GWh
  - NCAP_TLIFE = 10
  - STG_MAXCYC = 4000

<table>
<thead>
<tr>
<th>Season 1</th>
<th>Season 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>VAR_FIn</td>
<td>VAR_FOut</td>
</tr>
</tbody>
</table>

- Targeted cycles per year: 4000/10*1 = 40 GWh per year output
- Current cycling per year: 500 GWh/10 = 50 GWh
- Excess cycling: 50 / 40 = 1.25
- Additional capacity to support excess cycling: 1.25 – 1 = 0.25
A simple RES for testing purposes

<table>
<thead>
<tr>
<th>Technology</th>
<th>Installed capacity GW</th>
<th>Minimum operating level</th>
<th>Hourly ramping rate up and down</th>
<th>Minimum online and offline times</th>
</tr>
</thead>
<tbody>
<tr>
<td>NUCLEAR</td>
<td>3.2</td>
<td>60%</td>
<td>5%</td>
<td>24/24</td>
</tr>
<tr>
<td>GAS-CC</td>
<td>1.9</td>
<td>50%</td>
<td>50%</td>
<td>4/2</td>
</tr>
<tr>
<td>GAS-OC</td>
<td>0.1</td>
<td>20%</td>
<td>100%</td>
<td>1/1</td>
</tr>
<tr>
<td>HYDDAM</td>
<td>13.4</td>
<td>n/a</td>
<td>80%</td>
<td>1/1</td>
</tr>
<tr>
<td>PHS</td>
<td>3.2</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>
Demand for operational reserves

Reserve requirements:
FCR-type of reserve : exogenously given @ 90 MW
aFRR type of reserve : loss of largest grid element + probabilistic assessment @ 95% quantile
mFRR type of reserve : loss of largest grid element + probabilistic assessment @ 99% quantile

Symmetry in positive and negative reserves

Probabilistic assessment:
The whole FRR-type of reserve (aFRR + mFRR) :

- Solar production forecast error: 1.5%
- Wind production forecast error: 0.8%
- Demand forecast error: 1.7%

The dependency factor between aFRR and FRR is $\lambda=0.7$
Input parameters to model the example

Existing TIMES parameters to model dispatch features:
NCAP_PASTI to set existing capacities
ACT_TIME to set minimum online/offline times
ACT_UPS to set ramping rates and minimum stable operating level

NEW TIMES parameters to model ancillary markets:
BS_RTYPE to define the reserve commodities
BS_OMEGA to specify the reserve demand functions
BS_DEMDET to specify the deterministic component of the demands of the different reserves
BS_SIGMA to specify the probabilistic component of the demands of aFRR and mFRR, based on FRR
BS_LAMBDA to set the relationships between aFRR and FRR, as well as between mFRR and FRR
BS_RMAX to specify the contribution of each technology in reserves
Results on investment decisions – 3 scenarios

- **Base**
  - No peak constraint
  - No ancillary markets

- **Peak 30%**
  - No ancillary markets
  - Peak constraint 30%

- **Ancillary Markets**
  - No peak constraint
  - Ancillary markets

For the Peak 30% scenario:
The contribution to peak reserve from hydropower is 60%, from pump storage 50%. No contribution to peak reserve from solar & wind.
Results on operational decisions

Base and Peak 30% scenario

Ancillary markets scenario

Electricity production in Winter (GWh/h)
We force maintenance of up 30% of installed Gas-CC capacity for 5h

- $\text{NCAP}_{\text{AFS}}('\text{GAS-CC}', '\text{SUM}', '\text{UP}') = 0.7$
- $\text{BS}_{\text{MAINT}}('\text{GAS-CC}', '\text{SUM}')=5$

Maintenance of a Gas CC power plant for 5h

Offline capacity increases as plant shuts down for maintenance
Each GW of capacity entered into maintenance needs to stay offline for 5h
My thanks go to

• Antti Lehtilä

• Paul Deane

• Tarun Sharma

... and to the ETSAP ExCo for financing the project