Usage of TIMES at IER

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Overview

- Applications of TIMES at IER
- Features of TIMES
- Using ANSWER-TIMES
- Modifications to TIMES at IER

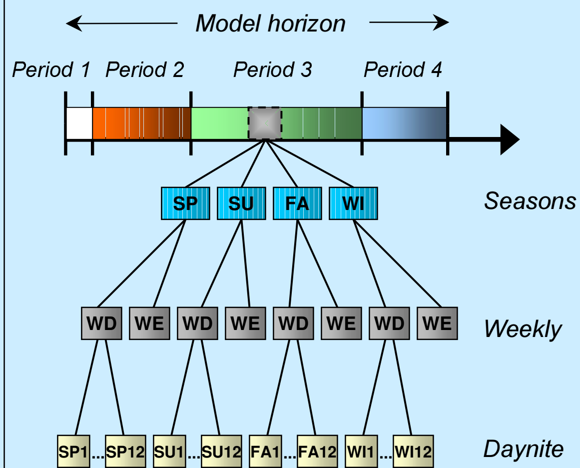
Application of TIMES at IER

- Models developed in TIMES
  - TIMES–BY: Model of Bavarian energy system
  - TIMES–GES: Model of German electricity sector disaggregated in seven regions
  - TIMES–D2: Two-regional model of German energy system
  - TIMES–D1: One-regional model of German energy system
  - TIMES–EE: Multi-regional model of the European electricity + public heat sector
  - World model: Two-regional model (OECD, Non-OECD)
- Diploma thesis on the development of a 4 regional model for the Nordic electricity sector (in cooperation with HUT/VTT)
- In cooperation with ERI conversion of national South African energy model (focusing on the conversion sector) from MARKAL to TIMES; part of an ongoing diploma thesis analyzing GHG and pollutant abatement strategies

Characteristic features of TIMES

- **Flexible multi-commodity process description**
- **Flexibility in time**
- **Vintaging and age-dependency of parameters**
- **Inter-regional exchange processes**
- **Framework to add user-specific constraints, including inter-temporal relations**
- **Detailled objective function**
- **Elastic demands**

Flexibility in time



- **Variable period length and unlimited # of periods**
- **Easy shifting of model horizon**
- **Timeslice tree with three sub-levels**
- **User-defined time-segment resolution for commodities and processes**
- **Inheritance and aggregation of parameters along the tree**
- **Time-slice storage as well as inter-period storage**
- **Load curve**

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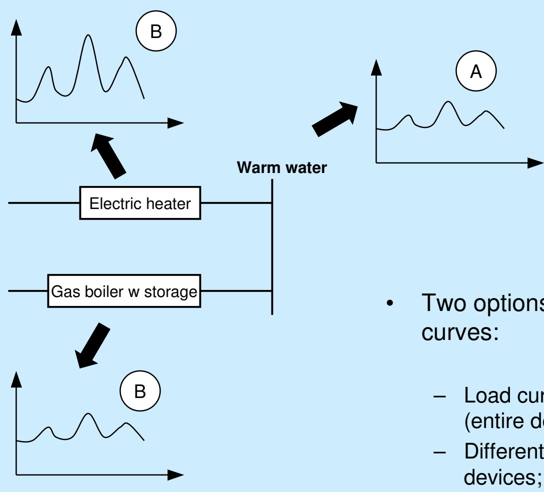
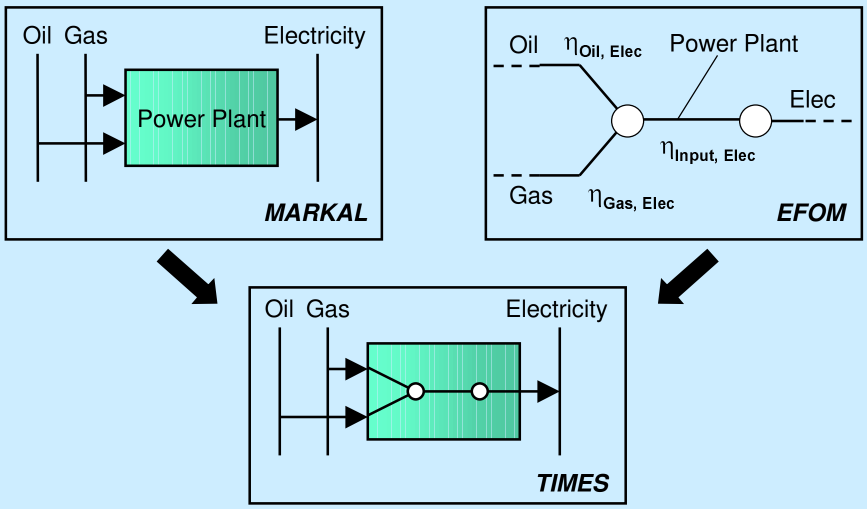
Flexibility in time – load curves



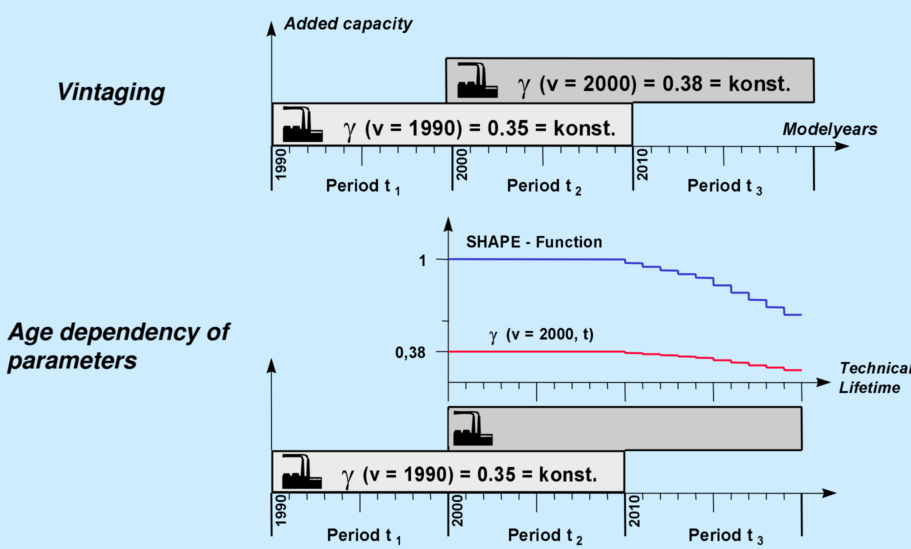
- Two options for defining demand load curves:
  - Load curve for the demand commodity (entire demand), case A
  - Different load curves for the demand devices; case B

Flexible process description



- **Transformation equation allows flexible input and output ratios**

Vintaging and age dependency of parameters



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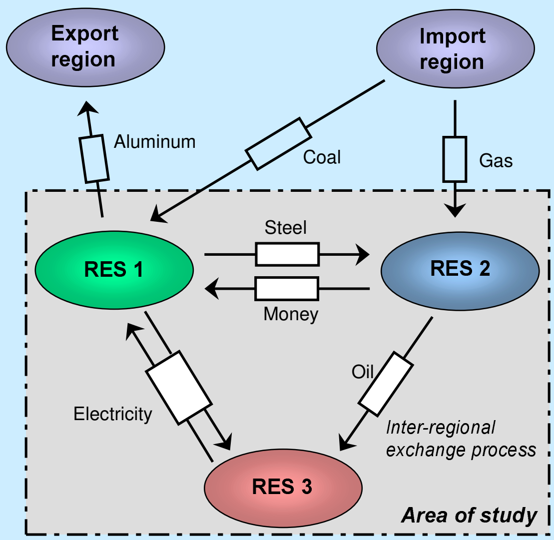
Inter-regional exchange



- Inter-regional exchange process between two internal regions similar to import/export process;
  thus:
  - easy linkage of different regions
  - modelling of trade

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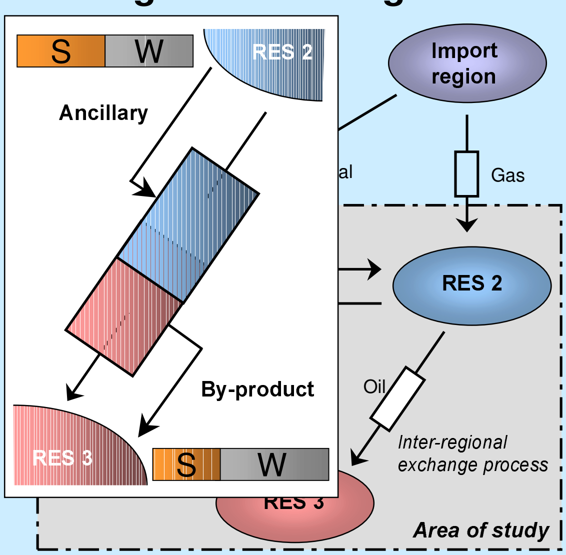
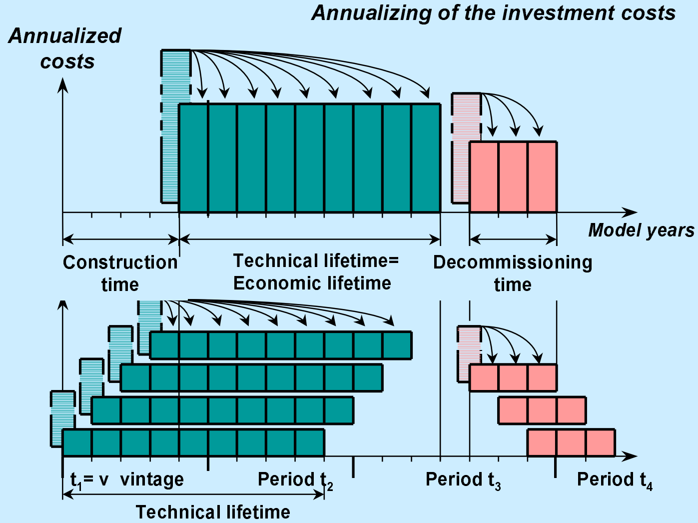
Inter-regional exchange



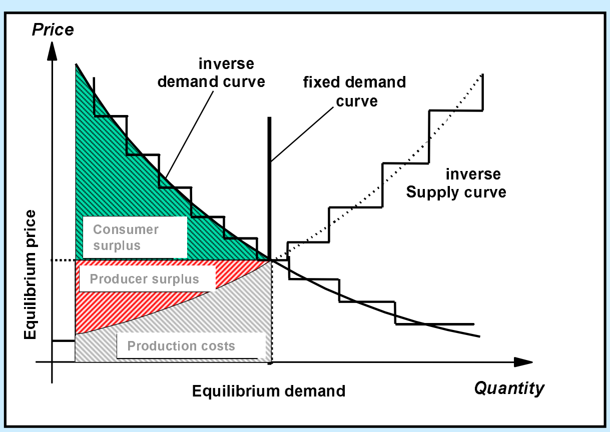
- Inter-regional exchange process between two internal regions similar to import/export process;
  thus:
  - easy linkage of different regions
  - modelling of trade
- Additional parameters for exchange processes between internal regions exist:
  - Ancillaries and by-products for exchange processes
  - Matrix for mapping time-slices in different regions

Objective function cont.

Annualizing of the investment costs



Elastic demands



Fixed demand

Min $\sum^{\text{Demand commodities}}$ Production costs

Max $\sum^{\text{Demand commodities}}$ [- Production costs + (Consumer surplus + Producer surplus + Production costs)]

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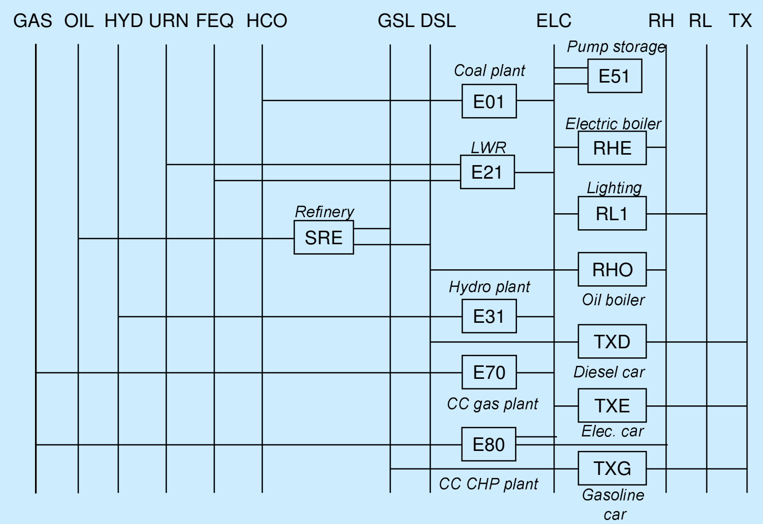
RES of Utopia



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Defining Processes

```
SET PRC
/
...
E02
...
/;
SET TOP (REG,PRC,COM,IO)
/
...
REG.E02.HCO.IN
REG.E02.ELC.OUT
...
/;

SET PRC_CG(REG,PRC,CG)
/
...
REG.E02.HCO
REG.E02.ELC
...
/;

SET
PRC_CAPUNT(REG,PRC,CG,UNITS_CAP)
/
...
REG.E02.ELC.GW
...
/;

SET
PRC_ACTUNT(REG,PRC,CG,UNITS_ACT)
/
...
REG.E02.ELC.PJ
...
/;
```

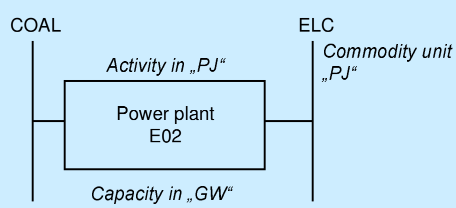
Process name

Topology

Commodity groups

Capacity unit

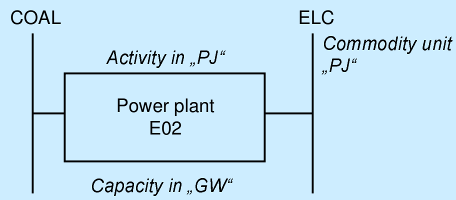
PCG E02 and activity unit in PJ




```
PARAMETER PRC_CAPACT(REG,PRC)
/
REG.E02     31.54
/;
```

Conversion from GW to PJ/a

Defining Processes- contd



- Investment costs : 1300 Mill. /GW
- Fixed O&M costs : 65 Mill. /GW
- Variable costs : 0.285 Mill. /PJ
- Lifetime : 35 a
- Efficiency : 0.43

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Recent extensions of TIMES at IER

- Market/product allocation constraints:
  - Bounding the share of a process flow in the total production/consumption of a commodity
  - Useful in calibrating model parts where choices not only depend on economic aspects (e. g. usage of a private car instead of public transport because of status, convenience and flexibility)
- Availability factor for backpressure and condensing mode of pass-out CHP turbine:
  - Limiting the number of backpressure mode full load hours, since with only a few number of time slices on the daynite level a pass-out turbine usually will be used only in backpressure mode, while in reality a pass-out turbine is used only during the heating season in backpressure mode and the rest of the year in condensing mode
  - (Note: for pass-out turbines the fuel input should be chosen as activity unit not the electricity commodity)
- Peaking equation:
  - Possibility of generating of peaking equation not for single commodity but for a commodity group, e. g. different electricity commodities

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Recent extensions of TIMES at IER - contd

- Discrete capacity extension:
  - Capacity can only be added in different predefined block sizes, which may have different specific investment costs, resulting in a MIP problem
- Average generation costs - report extension:
  - Calculation of average annual generation costs of a commodity or a process flow taking into account the fuel costs associated with activities prior in the process chain, e. g. coal extraction and transport costs are considered in the electricity generation costs of a coal power plant
  - Solution of a linear system of equations by adding a dummy objective function and using an LP solver
  - Similar calculations to obtain average CO_2 emissions or primary energy consumption per unit of output flow
- Reduction algorithm:
  - Different measures to reduce model size, e. g.:
    - Processes without capacity related parameters do not need capacity variables
    - Replacing flow variable by activity variable if Primary Commodity Group consists only of one commodity
  - Reduction of memory usage by up to 25 % in some cases
  - Solution times for reduced and non-reduced problem of barrier algorithm similar, however, improvement in simplex iterations after crossover to basis solution (using CPLEX 7.5)

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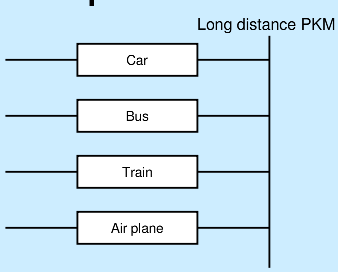
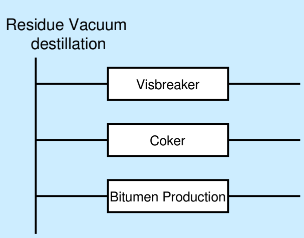
Market/product allocation constraint



Market allocation constraint

$$EQL(G/E)\_MRKSHR_{r,t,p,c,s}$$

$$\frac{\sum_{vintyr_{r,v,t,p}} \sum_{ts \in ts_{p,c}} VAR\_FLO_{r,v,t,p,c,s}\,\tau_{ts,s}}{\sum_{prc \in topout_{prc,c}} \sum_{vintyr_{r,v,t,prc}} \sum_{ts \in ts_{prc,c}} VAR\_FLO_{r,v,t,prc,c,ts}\,\tau_{ts,s}} \le (\ge =)\ flo\_mrkshr_{r,t,p,c,s}$$



Product allocation constraint

$$EQL(G/E)\_PRDSHR_{r,t,p,c,s}$$

$$\frac{\sum_{vintyr_{r,v,t,p}} \sum_{ts \in ts_{p,c}} VAR\_FLO_{r,v,t,p,c,s}\,\tau_{ts,s}}{\sum_{prc \in topin_{prc,c}} \sum_{vintyr_{r,v,t,prc}} \sum_{ts \in ts_{prc,c}} VAR\_FLO_{r,v,t,prc,c,ts}\,\tau_{ts,s}} \le (\ge =)\ flo\_prdshr_{r,t,p,c,s}$$

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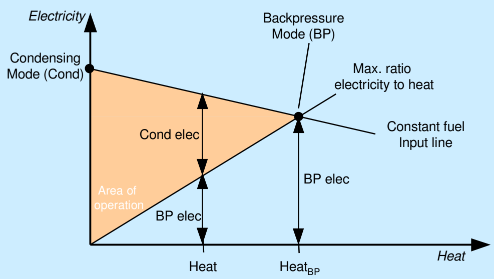
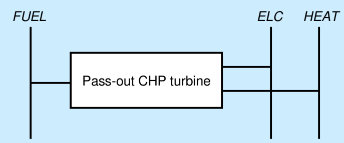
Modeling of pass-out (extraction-condensing) turbines





Description of constant fuel input line

$$VAR\_FLO_{fuel} = \frac{1}{\eta_{cond}}\left(VAR\_FLO_{ELC} + elp \cdot VAR\_FLO_{HEAT}\right)$$

$$reh \geq \frac{VAR\_FLO_{ELC}}{VAR\_FLO_{HEAT}}$$

η_{cond} : Condensing mode efficiency
reh : Max. Ratio of electricity to heat
elp : Electricity loss per heat unit

Conversion of capacity definitions

$$inp2cond = \eta_{cond}$$

$$inp2bpt = \frac{\eta_{cond}}{1 + \frac{elp}{reh}}$$

Inp2cond : Conversion factor from input capacity to condensing mode capacity
Inp2bpt : Conversion factor from input capacity to backpressure capacity electric

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Availability factors for backpressure and condensing mode

- Limiting the number of backpressure mode full load hours, since with only a few number of time slices on the daynite level a pass-out turbine usually will be used only in backpressure mode, while in reality a pass-out turbine is used only during the heating season in backpressure mode and the rest of the year in condensing mode

Limiting annual availability of backpressure mode

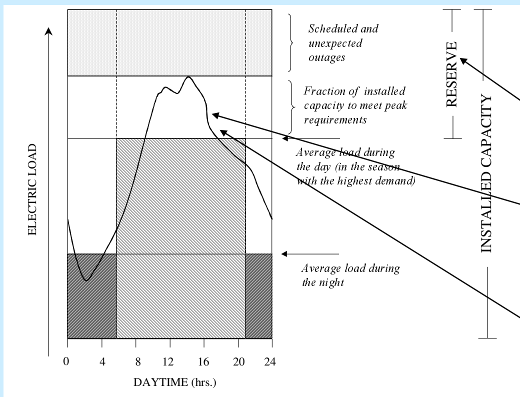
$$\sum_{v \in vintyr_{r,v,t,p}} cpt_{r,v,t,p} \cdot capact_{r,p} \cdot inp2bpt_{r,v,p} \cdot (VAR\_NCAP_{r,v,p} + pasti_{r,v,p}) \cdot afbpt_{r,v,p}$$
$$\geq$$
$$\sum_{c \in cheat_p} \sum_{v \in vintyr_{r,v,t,p}} \sum_{ts \in ts_{p,c}} reh_{r,v,p} \cdot VAR\_FLO_{r,v,t,p,c,ts}$$

Limiting annual availability of condensing mode

$$\sum_{v \in vintyr_{r,v,t,p}} cpt_{r,v,t,p} \cdot capact_{r,p} \cdot inp2con_{r,v,p} \cdot (VAR\_NCAP_{r,v,p} + pasti_{r,v,p}) \cdot afcon_{r,v,p}$$
$$\geq$$
$$\sum_{c \in cele_p} \sum_{v \in vintyr_{r,v,t,p}} \sum_{ts \in ts_{p,c}} VAR\_FLO_{r,v,t,p,c,ts} - \sum_{c \in cheat_p} \sum_{v \in vintyr_{r,v,t,p}} \sum_{ts \in ts_{p,c}} reh_{r,v,p} \cdot VAR\_FLO_{r,v,t,p,c,ts}$$

Peaking equation

- Peaking constraint ensures that the capacity installed is enough to meet the highest demand in any timeslice, taking into consideration both adjustments to the average demands tracked by the model and a reserve margin requiring excess capacity to be installed.



- Peaking commodity specified by set COM_PEAK(r,c) for all timeslices unless COM_PKTS(r,c,s)
- COM_PKRSV(r,t,c): Peak reserve margin
- COM_PKFLX(r,t,c,s): difference between the average calculated demand and the actual shape of the peak
- FLO_PKCOI(r,t,p,c,s): factor increasing the demand where peak usage is typically higher
- NCAP_PKCNT(r,t,p,s): fraction of capacity contributing to peak

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Peaking equation - contd

- Modification of peaking equation:
  – Possibility of generating of peaking equation not for single commodity but for a commodity group, e. g. different electricity commodities

Discrete capacity extension

- Discrete capacity extension:
  - Capacity can only be added in different predefined block sizes resulting in a MIP problem
  - Blocks may have different specific investment costs, e. g. specific costs are a concave function of the block size

$$VAR\_NCAP_{r,v,p} = \sum_j VAR\_NDSC_{r,v,p,j} \cdot ncap\_disc_{r,v,p,j} ; \forall\, rtp_{r,v,p}$$

$$\sum_j VAR\_NDSC_{r,v,p,j} = 1 \;; \forall\, rtp_{r,v,p} \quad (\Leftrightarrow \text{SOS1 set supported by some solvers})$$

$$VAR\_NDSC_{r,v,p,j} \in \{0;1\}$$

j: index for binary variables

$VAR\_NDSC_{r,v,p,j}$: binary variable

$ncap\_disc_{r,v,p,j}$: allowable sizes of capacity extensions

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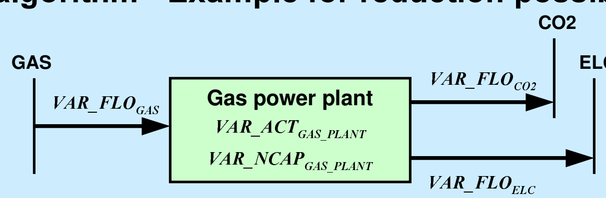
Reduction algorithm - Example for reduction possibilities



Process Equations		Substitution formulas
EQ_ACTFLO:	$VAR\_ACT_{GAS\_PLANT} = VAR\_FLO_{ELC}$	$\rightarrow VAR\_FLO_{ELC} = VAR\_ACT_{GAS\_PLANT}$
EQ_PTRANS:	$\eta\, VAR\_FLO_{GAS} = VAR\_FLO_{ELC}$	$\rightarrow VAR\_FLO_{GAS} = \frac{VAR\_ACT_{GAS\_PLANT}}{\eta}$
EQ_PTRANS:	$emis_{GAS}\, VAR\_FLO_{GAS} = VAR\_FLO_{CO2}$	$\rightarrow VAR\_FLO_{CO2} = emis_{GAS} \frac{VAR\_ACT_{GAS\_PLANT}}{\eta}$
EQ_CAPACT:	$VAR\_ACT_{GAS\_PLANT} \leq \sum_t VAR\_NCAP_{GAS\_PLANT,t} AF_{GAS\_PLANT} \tau_{ts}$	

- **System can be reduced by 3 variables and 3 equations.**

Reduction algorithm - Implemented reduction measures

- Processes without capacity related parameters do not need capacity variables
- Replacing flow variable by activity variable if Primary Commodity Group consists of one commodity
- FLO_FUNC between two commodities with one of them defining the activity => other flow variable can be expressed by activity variable and FLO_FUNC
- Replacing emission flow by fossil flow times emission factor
- Upper / Fixed activity bound of zero implies that all flow variables are zero => Flow variables and related equations can be removed

Reduction algorithm - Results

	Matrix size				Execution time		Memory Usage	
	no reduction		*with reduction*		*no reduction*	*with reduction*	*no reduction*	*with reduction*
	eqns	*vars*	*eqns*	*vars*				
"Aggressive" Reduction TIMES-D2	426,255	418,191	131,959	136,558	634 sec	652 sec	276 MB	196 MB
"Modest" Reduction TIMES-D2	426,255	418,191	146,586	153,737	634 sec	634 sec	276 MB	203 MB

	Solution time		Objective function	
	no reduction	*with reduction*	*no reduction*	*with reduction*
"Aggressive" Reduction TIMES-D2	1409 sec	1097 sec	16,041,290	16,039,728
"Modest" Reduction TIMES-D2	1409 sec	730 sec	16,041,290	16,039,730

With CPLEX 7.5

Reduction algorithm - Conclusions

- Number of equations and variables can be reduced by the factor 2-3
  - For larger models this leads to a reduction in memory usage.
  - Size of reduced matrix within CPLEX is not affected.
- Execution time in GAMS (Preprocessor + generating matrix) is similar.
- Solution time:
  - Solution time of Barrier algorithm is similar.
  - Time savings in solution time due to faster crossover to basic solution. Hence, overall solution of reduced and non-reduced problem are similar when crossover is turned off.
  - “The more reduction, the better” is not always true.
- Shadow price of substituted transformation equations (EQ_PTRANS) are lost, might be recovered from dual solution of reduced problem. Also reduced cost of activity variables with an upper/fixed bound of zero are lost. If this information is needed, one should use a very small number as upper / fixed bound (also generally recommended when analysing reduced costs for lower bounds of zero because of problem with reduced costs in CPLEX).
- Not yet tested effects on ETL (MIP problem)

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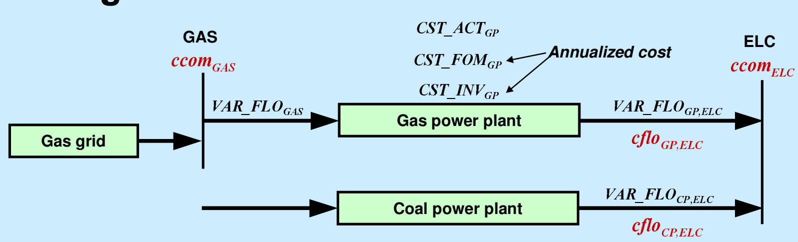
Average cost calculation



Average annual flow generation cost (case VAR_FLO defines activity)

$$cflo_{GP,ELC} = \frac{ccom_{GAS}\, VAR\_FLO_{GP,GAS} + CST\_ACT_{GP} + CST\_FOM_{GP} + CST\_INV_{GP}}{VAR\_FLO_{GP,ELC}}$$

Average annual commodity cost

$$ccom_{ELC} = \frac{cflo_{GP,ELC}\, VAR\_FLO_{GP,ELC} + cflo_{CP,ELC}\, VAR\_FLO_{CP,ELC}}{VAR\_FLO_{GP,ELC} + VAR\_FLO_{CP,ELC}}$$

VAR_FLOs, CST_ACT, CST_FOM, CST_INV are known.

Variables ; average annual flow generation cost *cflo* and average annual commodity generation cost *ccom*

- **Square system of equations solved in GAMS with a dummy objective function**
- **Solution written in VEDA file**