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Wilmar Joint Market Model Documentation

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Abstract:

The Wilmar Planning Tool is developed in the project Wind Power Integration in Liberalised Electricity Markets (WILMAR) supported by EU (Contract No. ENK5-CT-2002-00663).

A User Shell implemented in an Excel workbook controls the Wilmar Planning Tool. All data are contained in Access databases that communicate with various sub-models through text files that are exported from or imported to the databases. The Joint Market Model (JMM) constitutes one of these sub-models.

This report documents the Joint Market model (JMM). The documentation describes:

1. The file structure of the JMM.
2. The sets, parameters and variables in the JMM.
3. The equations in the JMM.
4. The looping structure in the JMM.

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Preface

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A User Shell implemented in an Excel workbook controls the Wilmar Planning Tool. All data are contained in Access databases that communicate with various sub-models through text files that are exported from or imported to the databases. The Joint Market Model (JMM) constitutes one of these sub-models as shown in Figure 1.

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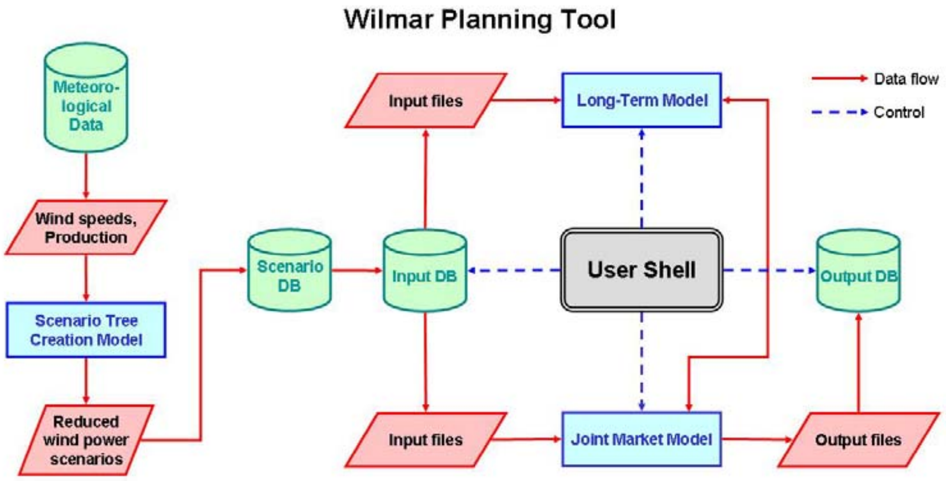

Figure 1: Overview of Wilmar Planning tool. The green cylinders are databases, the red parallelograms indicate exchange of information between submodels or databases, the blue squares are models. The user shell controlling the execution of the Wilmar Planning tool is shown in black.

Table 1: Basic information about the Joint Market model.

Authors	Heike Brand (first versions and supervision), Peter Meibom, Rüdiger Barth, Christoph Weber (supervision), Juha Kiviluoma
Development period	November 2002 – December 2005
Relation to other programs	See Figure 1.
Program language	GAMS* (General Algebraic Modeling System) with CPLEX 9.0
Location	http://www.wilmar.risoe.dk

* see www.gams.com for further information.

1 Introduction

1.1 Objectives of the Joint market model

The integration of substantial amounts of wind power in a liberalized electricity system will impact both the technical operation of the electricity system and the electricity market. In order to cope with the fluctuations and the partial unpredictability in the wind power production, other units in the power system have to be operated more flexibly to maintain the stability of the power system. Technically this means that larger amounts of wind power will require increased capacities of spinning and non-spinning power reserves and an increased use of these reserves. Moreover, if wind power is concentrated in certain regions, increased wind power generation may lead to bottlenecks in the transmission networks. Economically, these changes in system operation have certainly cost and consequently price implications. Moreover they may also impact the functioning and the efficiency of certain market designs. Even if the wind power production is not bided into the spot market, the feed-in of the wind power will affect the spot market prices, since it influences the balance of demand and supply.

As substantial amounts of wind power will require increased reserves, the prices on the regulating power markets are furthermore expected to increase. Yet this is not primarily due to the fluctuations of wind power itself but rather due to the partial unpredictability of wind power. If wind power were fluctuating but perfectly predictable, the conventional power plants would have to operate also in a more variable way, but this operation could be scheduled on a day-ahead basis and settled on conventional day-ahead spot markets. It is the unpredictability of wind power which requires an increased use of reserves with corresponding price implications.

In order to analyse adequately the market impacts of wind power it is therefore essential to model explicitly the stochastic behaviour of wind generation and to take the forecast errors into account. In an ideal, efficient market setting, all power plant operators will take into account the prediction uncertainty when deciding on the unit commitment and dispatch. This will lead to changes in the power plant operation compared to an operation scheduling based on deterministic expectations, since the cost functions for power production are usually non-linear and not separable in time. E.g. even without fluctuating wind power, start-up costs and reduced part-load efficiency lead to a trade-off for power plant operation in low demand situations, i.e. notably during the night. Either the power plant operator chooses to shut down some power plants during the night to save fuel costs while operating the remaining plants at full output and hence optimal efficiency. Or he operates a larger number of power plants at part load in order to avoid start-up costs in the next morning. This trade-off is modified if the next increase in demand is not known with (almost) certainty. So in an ideal world, where information is gathered and processed at no cost, power plant operators will anticipate possible future wind developments and adjust their power plant operation accordingly. The model presented in the following describes such an ideal and efficient market operation by using a stochastic linear programming model, which depicts ‘real world optimization’ on the power market on an hourly basis with rolling planning. With efficient markets, i.e. also without market power, the market results will correspond to the outcomes of a system-wide optimization as described in the following. The cost and price effects derived for the integration of wind energy in this model should then provide a lower bound to the magnitude of these effects in the real, imperfect world.

1.2 File structure of the Joint Market Model

The Joint Market model consists of a large number of files, which can be classified as follows:

1. Input data files: containing the data input to the JMM. When the generation of input files to the JMM model is activated, all queries in the input database with names starting with *"O Set"* or *"O Parameter"* are run and the results of these queries are exported to text files with names *"<Query name>.inc"*, cf. Chapter 2. The files are saved in folder *"base\model\inc_database"*.
2. Files containing the GAMS definitions of sets and parameters containing input data in the JMM (see Chapter 3). The files are saved in folder *"base\model\inc_structure_det"*. The input data files mentioned in point 1 above are included into these files.
3. Files containing GAMS code that generates the output files of the JMM (see Chapter 4). The files are saved in folder *"base\printinc"*.
4. The JMM model writes a series of output files containing the results of a JMM run named *"OUT_Xyz.csv"* where *"Xyz"* gives some information on the content of the file, cf. Chapter 5. These files are imported to the output database. The files are saved in folder *"base\model\Printout"*.
5. During the optimisation in the JMM model two status files *"SolveStatus.txt"* and *"ISolveStatus.txt"* are written, see Chapter 6.
6. Options files containing settings influencing the JMM run (Chapter 7). The setting of some of the options is done from the user shell and written in file *"Choice.gms"*. The files are saved in folder *"base\model"*.
7. The JMM model communicates with the Long Term Model LTM through several files (Chapter 8).
8. The main model file *"Wilmar1_12.gms"* containing the specification of the equations and looping structure of the JMM. Also internal sets and parameters (not holding input data) are defined in this file. The file is saved in folder *"base\model"*. The equations of the JMM are described in Chapter 9 and the looping structure of the JMM in Chapter 10. Finally the choices involved in the specification of the model used are described in Chapter 11.

2 Data input files

When the generation of input files to the JMM model is activated, all queries in the input database with names starting with *"O Set"* or *"O Parameter"* are run and the results of these queries are exported to text files with names *"<Query name>.inc"*. The syntax of these files is designed so that the files can be used directly as include files in a GAMS source file. The files are placed in folder *"Base\Model\Inc_Database"*.

2.1 Sets

There are 30 files *"O Set *.inc"* as listed in Appendix D. These files specify the set elements in the GAMS model. The table in Appendix D has the columns shown in Table 2.

Table 2: Content of table in Appendix D.

Heading	Content	Example
File	Name of the JMM input file.	O Set C.inc[1]
GAMS set	SET(s) in the GAMS model defined by this file.	CCC & C (CCC)
Type	Type of data.	Geography
Source table	The name of the table in the input database from which the data are queried.	Base Countries
Description	A short description of the data.	Countries

[1]: File *“O Set Abc.inc”* is exported from query *“O Set Abc”* in the input database.

2.2 Parameters

There are 49 files *“O Parameter *.inc”* as listed in Appendix E. These files hold all data needed to describe the energy system that is to be simulated by the JMM model. In Appendix E there are two tables describing the files.

The content of the first table in Appendix E is shown in Table 3.

Table 3: Content of first table in Appendix E.

Heading	Content	Example
File	Name of the JMM input file.	O Parameter FUELPRICE_GJ.inc[1]
Gams parameter	The GAMS parameter that receives the data.	FUELPRICE_PER_GJ
GAMS dependency	The set(s) that the GAMS parameter depends on.	YYY, AAA, FFF
Description	A short description of the data.	Fuel price for areas with own fuel price scenarios.
Unit	The unit for the data.	EUR2002/GJ

[1]: File *“O Parameter Abc.inc”* is exported from query *“O Parameter Abc”* in the input database.

The second table in Appendix E has the columns shown in Table 4.

Table 4: Content of second table in Appendix E.

Heading	Content	Example
File	Name of the JMM input file.	O Parameter FUELPRICE_GJ.inc
Source table	The main table in the input database from which the data are queried.	Data AAA YYY FFF Fuel Prices
Source field	The field in this database table.	AnnualFuelPrice

3 Files defining Sets and Parameters

Files defining GAMS definition of sets and parameters are contained in folder *"base\model\inc_structure_det"*. The input data files mentioned in Chapter 2 are included in these files.

Table 5: Files containing GAMS definition of sets and parameters.

File	Description
basevar.inc	Definition of parameters containing hourly time series
fuel.inc	Fuel data
fuelp.inc	Annually specified fuel prices
geogr.inc	Geographically specific values
gkfx_all.inc	Annually specified generation capacities
parameter_stoch.inc	Definition of stochastic parameters
sets.inc	Sets used in the program
sets_stoch.inc	Stochastic sets in the program
STARTVALUES.INC	Start values of the JMM run (hydro reservoir filling degree)
tech.inc	Technology data
trans.inc	Transmission data
Var.inc	Price-elastic demand

4 Output generation files

Folder *"base\Printinc"* contains files used to generate the output files from a JMM run. For each output parameter, variable or marginal value of an equation, a file writes the values of the output in question to a specific output file. The content of the output files is described in Chapter 5 and Appendix F. Normally only root node values are written out (i.e. stage 1 values), because these values are the final ones being determined in the optimisation run closest to the hours in question. Furthermore, the size of the output covering the whole scenario tree is very large. Table 6 shows the file names of the output generation files that are contained in folder *"base\Printinc"*.

File "*print_file_definition.inc"* contains the definition of file names and definition of sets used to generate the output. File *"print_results_node_t.inc"* selects the output to be written out by inclusion or exclusion of the files generating the output.

Table 6: Files containing GAMS code that generates the output files.

File names	
print_file_definition.inc	print-OUT_VELEC_CONTENTSTORAGE.inc
print_results_node_t.inc	print-OUT_VGE_ANCNEG.inc
print-isolvestatus.inc	print-OUT_VGE_ANCPOS.inc
print-OUT_BASETIME.inc	print-OUT_VGE_CONSUMED_ANCNEG.inc
print-OUT_CaseName.inc	print-OUT_VGE_CONSUMED_ANCPOS.inc
print-OUT_ELEC_CONS_T.inc	Print-OUT_VGE_CONSUMED_NONSP_ANCNEG.inc
print-OUT_FuelPrice.inc	Print-OUT_VGE_CONSUMED_NONSP_ANCPOS.inc
print-OUT_HEAT_CONS_T.inc	print-OUT_VGE_NONSPIN_ANCNEG.inc
print-OUT_IGELECCAPACITY_Y.inc	print-OUT_VGE_NONSPIN_ANCPOS.inc

File names

print-OUT_ISDP_HYDRORES.inc
print-OUT_ISDP_ONLINE.inc
print-OUT_ISDP_STORAGE.inc
print-OUT_IWIND_AVG_IR.inc
print-OUT_IWIND_REALISED_IR.inc
print-OUT_IX3COUNTRY_T_Y.inc
print-OUT_QANCNEGEQ_M.inc
print-OUT_QANCPOSEQ_M.inc
print-OUT_QEEQDAY_M.inc
print-OUT_QEEQINT_M.inc
print-OUT_QESTOVOLT_M.inc
print-OUT_QGONLSTART_M.inc
print-OUT_QHEQURBAN_M.inc
print-OUT_QHSTOVOLT_M.inc
print-OUT_QNONSP_ANCPOSEQ_M.inc
print-OUT_TechnologyData.inc
print-OUT_UNITGROUPS_IN_CASE.inc
print-OUT_VCONTENTHYDRORES_NT.inc
print-OUT_VDEMANDELECFLEXIBLE.inc
print-OUT_VGELEC.inc
print-OUT_VGELEC_CONSUMED.inc
print-OUT_VGELEC_CONSUMED_DNEG.inc
print-OUT_VGELEC_CONSUMED_DPOS.inc
print-OUT_VGELEC_DNEG.inc
print-OUT_VGELEC_DPOS.inc
print-OUT_VGFUELUSAGE.inc
print-OUT_VGHEAT.inc
print-OUT_VGHEAT_CONSUMED.inc
print-OUT_VGONLINE.inc
print-OUT_VGSTARTUP.inc
print-OUT_VHEAT_CONTENTSTORAGE.inc
print-OUT_VHYDROSPILLAGE.inc
print-OUT_VOBJ.inc
Print-OUT_VOBJ_R_T.inc
Print-OUT_VXE_NONSPIN_ANCPOS_T.inc
Print-OUT_VXELEC_DNEG_T.inc
Print-OUT_VXELEC_DPOS_T.inc
Print-OUT_VXELEC_T.inc

5 Output files

The JMM model writes a series of output files (comma-separated text files) with a header row with variable names. These files are named *“OUT_Xyz.csv”* where *“Xyz”* gives some information on the content of the file. The files are placed in folder *“Base\PrintOut”*.

When import of these files to the output database is activated, folder *“Base\PrintOut”* is searched for all files complying with the file mask *“OUT_*.csv”*. When a particular file, say *“OUT_Abcd.csv”*, has been found it is imported to database table *“Abcd”* using the names in the first row as field names.

The JMM generates 53 output files *“OUT_*.csv”* as listed in Appendix F. The table in Appendix F has the following columns shown in Table 7.

Table 7: Content of table in Appendix F.

Heading	Content	Example
OUT file	Name of the JMM output file.	OUT_FuelPrice.csv[1]
Out file header	The header line.	CaseID, AreaID, FuelName, Value[2]
Unit	The unit for the data.	EUR2002/MWh
Description	A short description of the data.	Fuel price for current simulation year.

[1]: File *“OUT_Abc.csv”* is imported to table *“Abc”* in the output database.

[2]: The comma separated text strings correspond to field names in the database table.

6 Status files

The JMM model writes two status files *“SolveStatus.txt”* and *“ISolveStatus.txt”* to the folder *“Base\PrintOut”*. *“SolveStatus.txt”* gives information on the progress of the optimisation and a short indication of possible errors. *“ISolveStatus.txt”* contains the same information supplemented with detailed information on any errors.

7 Control files

A control file *“Choice.gms”* is written by the User Shell. This file contains some GAMS statements reflecting the user’s choices regarding the deterministic or stochastic optimisation run as well as regarding the number of loops in the optimisation. The file is placed in folder *“Base\Model”*.

The control file *“Choice.gms”* is a simple GAMS include file. The syntax of this file can best be described by an example :

```
* Choice of stochastic or deterministic model.
* Yes = Deterministic, No = Stochastic.
$SetGlobal JMM_Det Yes

* Number of loops included in one run.
SCALAR LOOPRUNS /8/;

* The number of infotimes that are skipped
* before solving the model. Should be equal
* to 2+4*N with N being a positive integer.
SCALAR STARTLOOP /4/;
```

The file *“Cplex.opt”* contains settings influencing the running of the solver CLPEX used to solve the optimisation problem. The file is placed in folder *“Base\Model”*.

The file *“wilmargams.opt”* contains settings influencing the output written in the GAMS list file. The file is placed in folder *“Base\Model”*.

8 Communication with the LTM model

The JMM model communicates with the Long Term Model LTM through three files placed in folder *“Base\Model\LTM\LTMmed”*:

- *“WV1reg.med”*
- *“ResFillWstart.med”*
- *“WVcalib.med”*

File *“WV1reg.med”* gives water values as function of hydro reservoir filling and week number, assuming a one region hydro reservoir model. The unit is EUR2002/MWh. The file is recalculated once a day by the LTM.

File *“ResFillWstart.med”* gives the relative filling of hydro reservoirs for each region and for the week in question. It is written by the JMM each time a day has been simulated, and is used by the JMM to lookup water values in file *“WV1reg.med”*.

File *“WVcalib.med”* holds weekly hydro power production as calculated by the LTM. It is used by the JMM to calibrate water values read from file *“WV1reg.med”*.

The LTM is activated from a JMM run by calling the file *“base\model\LTM2.gms”*.

9 Model description

In a liberalized market environment it is possible not only to change the unit commitment and dispatch, but even to trade electricity at different markets. The fundamental model analyses power markets based on a hourly description of generation, transmission and demand, combining the technical and economical aspects, and it derives hourly electricity market prices from marginal system operation costs. This is done on the basis of an optimisation of the unit commitment and dispatch taking into account the trading activities of the different actors on the considered energy markets. In this model four electricity markets and one market for heat are included:

1. A day-ahead market for physical delivery of electricity where the EEX market at Leipzig is taken as the starting point. This market is cleared at 12 o'clock for the following day and is called the day-ahead market. The nominal electricity demand is given exogenously.
2. An intra-day market for handling deviations between expected production agreed upon the day-ahead market and the realized values of production in the actual operation hour. Regulating power can be traded up to one hour before delivery. In this model the demand for regulating power is caused by the forecast errors connected to the wind power production.
3. A day-ahead market for automatically activated reserve power (frequency activated or load-flow activated). The demand for these ancillary services is determined exogenously to the model.
4. An intra-day market for positive secondary reserve power (minute reserve) mainly to meet the N-1 criterion and to cover the most extreme wind power forecast scenarios that are neglected by the scenario reduction process. Hence, the demand for this market is given exogenously to the model.
5. Due to the interactions of CHP plants with the day-ahead and the intra-day market, an intra-day market for district heating and process heat is also included in model. Thereby the heat demand is given exogenously.

The model is defined as a stochastic linear programming model (Birge and Louveaux, 2000), (Kall and Wallace, 1994). The stochastic part is presented by a scenario tree for possible wind power generation forecasts for the individual hours. The technical consequences of the consideration of the stochastic behaviour of the wind power generation is the partitioning of the decision variables for power output, for the transmitted power and for the loading of electricity and heat storages: one part describes the different quantities at the day-ahead market (thus they are fixed and do not vary for different scenarios). The other part describes contributions at the intra-day-market both for up- and down-regulation. The latter consequently depends on the scenarios. So for the power output of the unit group i at time t in scenario s we find $P_{i,s,t} = P_{i,t}^{DAY\_AHEAD} + P_{i,s,t}^{+} - P_{i,s,t}^{-}$. The variable $P_{i,t}^{DAY\_AHEAD}$ denotes the energy sold at the day-ahead market and has to be fixed the day before. $P_{i,s,t}^{+}$ and $P_{i,s,t}^{-}$ denote the positive and negative contributions to the intra-day market. Analogously the decision variables for the transmitted power and the loading of electricity and heat storages are defined accordingly.

Further the model is defined as a multi-regional model (cf. Figure 2). Each country is sub-divided into different regions, and the regions are further sub-divided into different areas. Thus, regional concentrations of installed wind power capacity, regions with comparable low demand and occurring bottlenecks between the model regions can be considered. The subdivision into areas allows considering individual district heating grids.

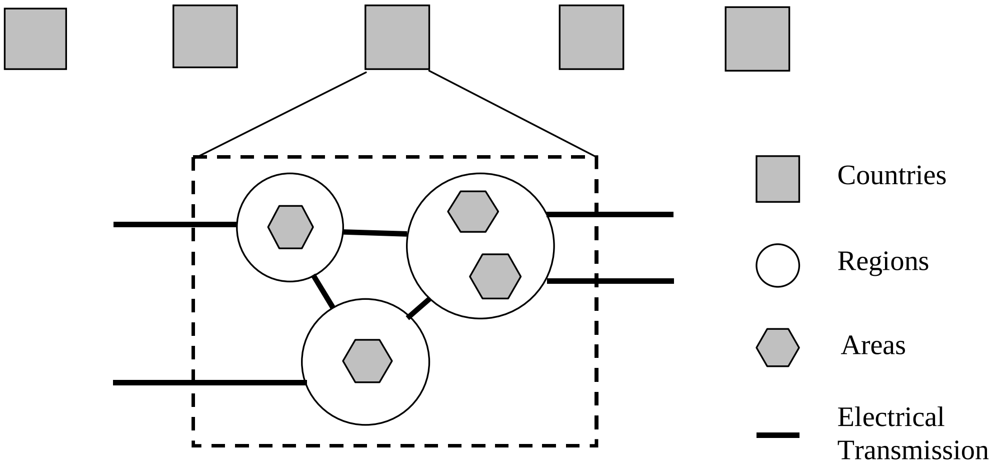

Figure 2: Illustration of the geographical entities and the transmission possibilities

9.1 Sets, parameters and decision variables

The used labelling of sets, parameters and decision variables for the documentation of the objective function and restrictions is listed in Table 8, Table 9 and Table 10, respectively.

The name in the programme code of the set, parameter or variable (compare appendix A, B and C) is indicated in the end of the description of each set, parameter or variable.

Table 8: Sets in the model.

Sets	Description
a, A	Index/ set of areas. IA, AAA
F	Set of used fuels. FFF
i, I	Index/ set of unit groups. G
$I^{BACKPRESSURE}$	Set of unit groups with backpressure turbines. IGBACKPR
I^{CHP}	Set of combined heat and power producing unit groups. IGELECANDHEAT
I^{ELEC}, I_r^{ELEC}	Set of power producing unit groups, set of power producing unit groups in region r. IGELEC
I^{ELEC_ONLY}	Set of unit groups producing only power. IGELECONLY
$I^{ELECSTORAGE}$	Set of electricity storages (e. g. pumped hydro storages). IGELECTSTORAGE
$I^{EXTRACTION}$	Set of unit groups with extraction-condensing turbines. IGEXTRACTION
I^{HEAT}, I_a^{HEAT}	Set of heat producing unit groups, set of heat producing unit groups in area a. IGHEAT(G)
$I^{HEATONLY}$	Set of unit groups producing only heat (i. e. heat boiler, heat pump, heat storage). IGHEATONLY(G)

Sets	Description
$I^{HEATPUMP}$	Set of electric heat pumps. IGHEATPUMP
$I^{HEATSTORAGE}$	Set of heat storages. IGHEATSTORAGE
I^{HYDRO}, I_r^{HYDRO}	Set of hydro storages, set of hydro storages in region r. IGHYDRORES
I^{ONLINE}	Set of unit groups with minimum restriction for power production. IGONLINE
I^{RAMP}	Set of unit groups for which a ramp rate < 1 is defined. IGRAMP
I^{SPIN}	Set of spinning unit groups. IGSPINNING
$I^{STORAGE}$	Set of storages with loading capacity, i.e. electricity and heat storages. IGSTORAGE
I^{USING_FUEL}	Set of unit groups using fuel. IGUSINGFUEL
k, K^{UP}, K^{DOWN}	Set of price flexible power demand steps on the day-ahead market, K^{UP} steps that increase demand relatively to nominal power demand, K^{DOWN} downward steps. DEF_U/DEF_D
r, R	Index/ set of regions. IR, RRR
$R_r^{NEIGHBOUR}$	Set of regions, which are the neighbour regions of region r
s, S	Index/ set of scenarios. NODE
t, T	Set of time steps t within a scenario tree, T describes the last time step within a scenario tree. T, IENDTIME(T)
T^{NOT_FIXED}	Time steps where the decision variables of the day-ahead market are not fixed. ITSPOTPERIOD(T)

Table 9: Parameters in the model.

Parameters	Description
$c_i^{START\_UP}$	Cost parameter of unit group i for the start-up of additional capacity. GDATA(IA,G,'GDSTARTUPCOST')
$d_{r,t}^{ANC,UP}, d_{r,t}^{ANC,DOWN}$	Demand for ancillary reserve (up/down regulation). IDEMAND_ANCPOS/IDEMAND_ANCNEG
$d_{r,t}^{ELEC}$	Nominal demand for time step t in region r. IDEMANDELEC
$d_{r,t}^{ELEC,EXPORT}$	Electricity export from region r to third countries at time step t
$d_{a,t}^{HEAT}$	Heat demand for time step t in area a. IDEMANDHEAT
$DISLOSS\_H$	Heat distribution loss. DISLOSS_H
$d_{r,s,t}^{NONSP,ANC,UP}$, $d_{r,t}^{NONSP,ANC,DOWN}$	Demand for non-spinning secondary reserve (up regulation). IDEMAND_NONSPIN_ANCPOS
e_i	Fuel consumption parameter for unit group i when online. GDATA(IA,G,’GDSECTION’)
f_i	Fuel consumption parameter for unit group i when producing power depending on the efficiency at the actual load. GDATA(IA,G,’GDSLOPE’)
$f_F^{EMISSION}$	Emission of CO_2 or SO_2 when burning fuel F. FDATA(FFF,'FDCO2') or FDATA(FFF,'FDSO2')
$f_{F,r}^{PRICE}$	Fuel price of fuel F in region r. IFUELPRICE_Y
$f_{F,r}^{SUBSIDY}$	Subsidy for power produced on plants using biomass or waste. ELEC_SUBSIDY(C,FFF)
$f_{EMISSION}^{TAX}$	Tax on emission of CO_2 or SO_2 from power plants. M_POL('TAX_CO2',C) or M_POL('TAX_SO2',C)
$f_{F,r}^{TAX}$	Tax of using fuel F in unit group i. GDATA(IA,G,'GDFUELTAX')

Parameters	**Description**
$f_{HEATPUMP,r}^{TAX}$	Tax of using electricity in heat pumps. TAX_HEATPUMP
$H_{i,t}^{MIN\_BOUND}$	Minimum bound on heat production. IHEATGEN_LOWBOUND_VAR_T
$i_{i,t}^{INFLOW}$	Natural inflow into hydro storage i at time step t. IHYDROINFLOW_T_Y
$i_{i,t}^{RUNRIVER}$	Production of run-of-river power plant i at time step t. IRUNRIVER_VAR_T
$i_{i,t}^{SOLAR}$	Production of solar plant i at time step t. ISOLAR_VAR_T
$LOADLOSS$	Factor considering the load loss of electricity and heat storages. GDATA(IA,G,'GDLOADLOSS')
$l_{r,\bar{r}}^{TRANS,COST}$	Transmission cost per MWh. XCOST
$l_{r,\bar{r}}^{TRANS,MAX}$	Maximum transmission capacity from region r to $\bar{r}$. IXCAPACITY_Y
o_i	Operation and maintenance cost parameter for unit group i. GDATA(IA,G,'GDOMVCOST')
$p_{r,s,t}^{ACTUAL\_WIND}$	Actual wind power production capacity in region r, in scenario s at time step t. IWIND_REALISED_IR
$p_{r,t}^{BID\_WIND}$	Expected wind power production in region r at time step t when the day-ahead market is cleared (12 o’clock). IWIND_BID_IR
$p_{r,t}^{EXPECTED\_WIND}$	Expected wind power production in region r at time step t. IWIND_AVG_IR
$p_{r,k,t}^{FLEXIBLE\_PRICE}$	Price of flexible demand step. IDEFLEXIBLEPRICE_T
$p_i^{GKDERATE}$	Availability factor for unit group i. IGKDERATE
$p_i^{MAX\_PROD}$	Maximum electricity capacity of unit group i. IGELECCAPACITY_Y
$p_i^{MIN\_PROD}$	Minimum electricity capacity factor of unit group i, when unit group i is online. GDATA(IA,G,'GDMINLOADFACTOR')
$p_{r,t}^{WATERVALUE}$	Value of water in hydro storages in region r at time step t. ISDP_HYDRORES
$q_i^{MAX\_PROD}$	Maximum heat capacity of unit group i (only for heat generating unit groups). IGHEATCAPACITY_Y
$RAMPRATE$	Maximum increase of power production within an hour relative to the installed capacity. GDATA(IA,G,'GDRAMP')
$Sp_{i\in I^{ELECSTORAGE},s,T}^{ELECSTORAGE}$	Shadow value for electricity storage content at the end of a scenario tree. ISDP_STORAGE
$Sp_{i\in I^{HEATSTORAGE},s,T}^{HEATSTORAGE}$	Shadow value for heat storage content at the end of a scenario tree. ISDP_STORAGE
$Sp_{i\in I^{HYDRO},s,T}^{HYDRO}$	Shadow value for hydro storage content at the end of a scenario tree. ISDP_HYDRORES
$Sp_{i\in I^{ONLINE},s,T}^{ONLINE}$	Shadow value for unit group i being online at the end of a scenario tree. ISDP_ONLINE
$t_i^{LEADTIME}$	Leadtime of unit group i. GDATA(IA,G,'GDLEADTIME')
$t_i^{MIN\_OP}$	Minimum operation time of unit group i. GDATA(IA,G,'GDMINOPERATION')
$t_i^{MIN\_SD}$	Minimum shut down times of unit group i. GDATA(IA,G,'GDMINSHUTDOWN')
w_i^{MAX}	Maximum loading capacity of electricity or heat storage i. IGSTOLOADCAPACITY_Y
$XLOSS$	Transmission loss proportional to transmitted energy. XLOSS(IRE,IR)

Parameters	Description
δ_i^{CB}	Heat ratio of CHP turbine i. GDATA(IA,G,'GDCB')
$\eta_i^{FULLLOAD}$	Efficiency of unit group i at full load. GDATA(IA,G,’GDFULLLOAD’)
γ_{i}	Reduction of electric power production due to heat production of CHP turbine i. GDATA(IA,G,'GDCV')
$v_i^{ELECSTORAGE,MAX}$	Maximum storage content of electricity storage i. IGSTOCONTENTCAPACITY_Y
$v_i^{HEAT,MAX}$	Maximum storage content of heat storage i. IGSTOCONTENTCAPACITY_Y
$v_i^{HYDRO,MAX}$	Maximum storage content of hydro storage i. IGHYDRORESCONTENTCAPACITY_Y
$v_i^{HYDRO,MIN}$	Minimum storage content of hydro storage i. IGHYDRORESMINCONTENT_Y
π_s	Occurrence probability of scenario s. IPROBREACHNODE

Table 10: Decision variables in the model.

Decision variables	Description
$D_{r,k,t}^{FLEX\_DAY-AHEAD}$	Amount of flexible demand activated for price step k. VDEMANDELECFLEXIBLE_T
$F_{r,s,t}$	Fuel usage in region r in scenario s at time step t. VGFUELUSAGE_NT
$P_{i,s,t}$	Realised power output of unit group i in scenario s at time step t. No name
$P_{i,s,t}^{+}$, $P_{i,s,t}^{-}$	Down / up-regulation for balancing market of turbine i in scenario s at time step t. VGELEC_DPOS_NT/ VGELEC_DNEG_NT
$P_{r,\bar{r},s,t}$	Realised transmission of power from region r to region $\bar{r}$ in scenario s at time step t. No name
$P_{i,t}^{ANC,+}$, $P_{i,t}^{ANC,-}$	Contribution of unit group i to ancillary reserve (up/down regulation) at time step t. VGE_ANCPOS/VGE_ANCNEG
$P_{i,t}^{DAY\_AHEAD}$	Power of turbine i sold to day-ahead market at time step t. VGELEC_T
$P_{i,t}^{DAY\_AHEAD,WINDSHED}$	Wind power shedding of wind power plant i at the day-ahead market for time step t. VWINDSHEDDING_DAY_AHEAD
$P_{i,s,t}^{NONSP,ANC,+}$, $P_{i,s,t}^{NONSP,ANC-}$	Contribution of unit group i to non-spinning secondary reserve (up/down regulation) in scenario s at time step t. VGE_NONSPIN_ANCPOS
$P_{i,s,t}^{ONLINE}$	Online capacity of unit group i at time step t. VGONLINE_NT
$P_{i,s,t}^{STARTUP}$	Started capacity of unit group i in scenario s at time step t. VGSTARTUP_NT
$P_{r,\bar{r},s,t}^{TRANS,+}$, $P_{r,\bar{r},s,t}^{TRANS,-}$	Contribution to up / down regulation at balancing market in region $\bar{r}$ by increased/decreased transmission of power from region r to region $\bar{r}$ in scenario s at time step t. VXELEC_DPOS_NT/VXELEC_DNEG_NT
$P_{r,\bar{r},t}^{TRANS,DAY-AHEAD}$	Planned transmission from region r to region $\bar{r}$ when bidding on the day-ahead market. VXELEC_T
$P_{r,\bar{r},s,t}^{TRANS,NONSP,ANC,+}$, $P_{r,\bar{r},s,t}^{TRANS,NONSP,ANC,-}$	Reservation of up / down regulation at non-spinning secondary reserve market in region $\bar{r}$ by increased/decreased transmission of power from region r to region $\bar{r}$ in scenario s at time step t. VXE_NONSPIN_ANCPOS
$P_{r,s,t}^{WIND,-}$	Wind shedding of wind power plant i at the intra-day market in scenario s at time step t. VGELEC_DNEG_NT(IA,IGWIND,NODE,T)

Decision variables	Description
$Q_{i,s,t}$	Realised heat output of unit group i in scenario s, at time step t. VGHEAT_NT
$V_{i,s,t}^{ELECSTORAGE}$	Content of electricity storage i in scenario s at time step t. VCONTENTSTORAGE_NT
$V_{i,s,t}^{HEATSTORAGE}$	Content of heat storage i in scenario s at time step t. VCONTENTSTORAGE_NT
$V_{i,s,t}^{HYDRO}$	Content of hydro storage i in scenario s at time step t. VCONTENTHYDRORES_NT
$W_{i,s,t}$	Realised loading of electricity storage i or electricity consumption of heat pump i in scenario s at time step t. No name
$W_{i,s,t}^{+}$, $W_{i,s,t}^{-}$	Down / up regulation at intra-day market of electricity storage i in scenario s at time step t. VGELEC_CONSUMED_DPOS_NT /VGELEC_CONSUMED_DNEG_NT
$W_{i,t}^{ANC,+}$, $W_{i,t}^{ANC,-}$	Contribution of electricity storage i to ancillary reserve (down/up regulation). VGE_CONSUMED_ANCPOS/ VGE_CONSUMED_ANCNEG
$W_{i,t}^{DAY-AHEAD}$	Fixed loading capacity of electricity storage i at the day-ahead market. VGELEC_CONSUMED_NT
$W_{i,s,t}^{HEAT}$	Loading of heat storage i in scenario s at time step t. VGHEAT_CONSUMED_NT
$W_{i,s,t}^{NONSP,ANC+}$, $W_{i,s,t}^{NONSP,ANC-}$	Contribution of electricity storage i to non-spinning secondary reserve (down / up regulation) in scenario s at time step t. VGE_CONSUMED_NONSP_ANCPOS

9.2 Objective function and restrictions

In the following equations the name of the equation in the model code is given in the start of the equation.

The objective function (1) minimizes the total operation costs *Vobj* in the whole considered system. The first summand of the objective function describes the fuel costs. The following three summands consider the operation and maintenance costs of electricity and heat production. The next summand determines the costs due to starting additional capacity and in the following summand transmission costs are considered.

Next fuel taxes are determined followed by the tax on power used in heat pumps. The actual implementation of the fuel taxes in the model is more complicated than shown in (1), because the tax schemes differ between countries. The emission taxes on CO_2 and SO_2 are considered in the next line. The effect of SO_2 emission reduction equipment is taken into account in the model when calculating the SO_2 tax. The subsidy for power production based on biomass or waste is taken into account by the next summand.

The value of power plant units being online, the value of stored water in hydro storages and the value of the content of electricity and heat storages at the last time step T of a scenario tree reduces the total operation costs. The values for unit groups being online and for electricity and heat storages are determined by the shadow values of the respectively equations (28), (40) and (45) in a previous planning loop (see Chapter 10 for an explanation of the calculation of these shadow values). The values for the content of hydro storages are derived with a further model that optimizes the fill level of hydro storages in the long-term over a year, cf. (Meibom et al, 2004).

Price flexible power demand on the day-ahead market is represented by the two last summands with the increase in consumer surplus when consumption is increased and the decreased in consumer surplus when demand is reduced.

In the actual model code the increase in system costs when slack variables are activated is also included in QOBJ although not shown in (1).

QOBJ:

$\min Vobj =$	Objective function	
$\sum_{i \in I^{USING\_FUEL}} \sum_{s \in S} \sum_{t \in T} \pi_s F_{r,s,t} f_{F,r}^{PRICE}$	Fuel costs.	
$+ \sum_{i \in I^{ELEC}} \sum_{s \in S} \sum_{t \in T} \pi_s o_i P_{i,s,t}$	Variable O&M costs.	
$+ \sum_{i \in I^{CHP}} \sum_{s \in S} \sum_{t \in T} \pi_s o_i \gamma_i Q_{i,s,t}$	Variable O&M costs.	
$+ \sum_{i \in I^{HEATONLY}} \sum_{s \in S} \sum_{t \in T} \pi_s o_i Q_{i,s,t}$	Variable O&M costs.	
$+ \sum_{i \in I^{ONLINE}} \sum_{s \in S} \sum_{t \in T} \pi_s c_i^{STARTUP} P_{i,s,t}^{STARTUP}$	Start-up costs.	
$+ \sum_{r,\bar{r}} \sum_{s \in S} \sum_{t \in T} \pi_s l_{r,\bar{r}}^{TRANS,COST} P_{r,\bar{r},s,t}$	Transmission costs.	
$+ \sum_{i \in I^{USING\_FUEL}} \sum_{s \in S} \sum_{t \in T} \pi_s F_{r,s,t} f_{F,r}^{TAX}$	Fuel tax.	
$+ \sum_{i \in I^{HEATPUMP}} \sum_{s \in S} \sum_{t \in T} \pi_s f_{HEATPUMP,r}^{TAX} W_{i,s,t}$	Electricity tax for heat pumps.	(1)
$+ \sum_{i \in I^{USING\_FUEL}} \sum_{s \in S} \sum_{t \in T} \pi_s F_{r,s,t} f_F^{EMISSION} f_{EMISSION}^{TAX}$	Tax on emission of CO_2 and SO_2.	
$- \sum_{i \in I^{USINFG\_FUEL}} \sum_{s \in S} \sum_{t \in T} \pi_s f_{F,r}^{SUBSIDY} P_{i,s,t}$	Subsidy for power produced on plants using biomass or waste.	
$- \sum_{i \in I^{ONLINE}} \sum_{s \in S} \sum_{T} \pi_s Sp_{i \in I^{ONLINE},s,T}^{ONLINE} P_{i \in I^{ONLINE},s,T}^{ONLINE}$	Shadow price for units being online at the end of a scen. tree.	
$- \sum_{i \in I^{HYDRO}} \sum_{s \in S} \sum_{T} \pi_s Sp_{i \in I^{HYDRO},s,T}^{HYDRO} V_{i \in I^{HYDRO},s,T}^{HYDRO}$	Shadow price for hydro storage content at the end of a scen. tree.	
$- \sum_{i \in I^{STORAGE}} \sum_{s \in S} \sum_{T} \pi_s Sp_{i \in I^{ELECSTORAGE},s,T}^{ELECSTORAGE} V_{i \in I^{STORAGE},s,T}^{ELECSTORAGE}$	Shadow price for elec. storage content at the end of a scen. tree.	
$- \sum_{i \in I^{STORAGE}} \sum_{s \in S} \sum_{T} \pi_s Sp_{i \in I^{HEATSTORAGE},s,T}^{HEATSTORAGE} V_{i \in I^{STORAGE},s,T}^{HEATSTORAGE}$	Shadow price for heat storage content at the end of a scen. tree.	
$- \sum_{t=1}^{T} \sum_{r \in R} \sum_{k \in K^{UP}} D_{r,k,t}^{FLEX\_DAY-AHEAD} p_{r,k,t}^{FLEXIBLE\_PRICE}$	Increase in consumer surplus due to increased demand.	
$+ \sum_{t=1}^{T} \sum_{r \in R} \sum_{k \in K^{DOWN}} D_{r,k,t}^{FLEX\_DAY-AHEAD} p_{r,k,t}^{FLEXIBLE\_PRICE}$	Decrease in consumer surplus due to decreased demand.	

9.2.1 Market restrictions for the balance of supply and demand

The demand constraint is split up into two constraints: one balance equation for the power sold at the day-ahead market and one balance equation for the power sold at the intra-day market. The constraint for the time steps, where the day-ahead market is optimised (i.e. at 12 o'clock), is defined in (2). The equation requires that the sum of the power produced including the expected wind power production plus the imported power minus the planned wind power shedding equals the sum of the exported power to third countries that are not considered in the model plus the power used for loading electricity storages and electric heat pumps plus the exported power to other regions plus the electricity demand modified with the amounts of price flexible consumption activated. The variable considering wind power shedding at the day-ahead market can be turned off with the use of a binary parameter not shown in (2). The same applies for the price flexible demand (See Chapter 11 for an explanation of the model selections that can be done using binary parameters).

QEEQDAY:

$$\begin{aligned}
&\sum_{i\in I_r^{ELEC}} P_{i,t}^{DAY\_AHEAD} + i_{i,t}^{RUNRIVER} + i_{i,t}^{SOLAR} + p_{r,t}^{BID\_WIND} - P_{r,t}^{DAY\_AHEAD,WIND\_SHED} \\
&+\sum_{r}(1-XLOSS)\cdot P_{\bar{r},r,t}^{TRANS,DAY-AHEAD} \\
&=\sum_{r} d_{r,t}^{ELEC,EXPORT} + \sum_{i\in I_r^{ELECSTORAGE}\cup I_r^{HEATPUMP}} W_{i,t}^{DAY\_AHEAD} \\
&+\sum_{\bar{r}\in R_r^{NEIGHBOUR}} P_{r,\bar{r},t}^{TRANS} + d_{r,t}^{ELEC} + \sum_{k\in K^{UP}} D_{r,k,t}^{FLEX,+} - \sum_{k\in K^{DOWN}} D_{r,k,t}^{FLEX,-} \\
&\qquad \forall t\in T^{NOT\_FIXED}, \forall r\in R
\end{aligned} \tag{2}$$

If the expected wind power production is higher than the actual wind power production, a demand for up regulation exists. Conversely, there exists a demand for down regulation if the expected wind power production is lower than the actual one. The balance equation for the balancing market is described by the following equation (3). The up and down regulation of the unit groups and the up and down regulation of the loading of electricity storages as well as the up and down regulation by increased / decreased import has to be equal to the difference between the expected wind power production at the bidding hour of the day-ahead market (thereby the possible wind shedding at the day-ahead market has to be considered) and the actual wind power production minus the decreased / increased export. As the model allows wind shedding also at the intra-day market, the term $P_{r,s,t}^{WIND,-}$ is added to the equation. Further the consideration of increased / decreased import or export can be turned off using a binary parameter, i.e. a model run that do not allow transmission of regulating power can be run.

QEEQINT:

$$\begin{aligned}&\sum_{i\in I_r^{ELEC}}(P_{i,s,t}^{+}-P_{i,s,t}^{-})+\sum_{i\in I_r^{ELECSTORAGE}\cup I_r^{HEATPUMP}}(W_{i,s,t}^{+}-W_{i,s,t}^{-})\\&+\sum_{r,\bar{r}}(1-XLOSS)(P_{\bar{r},r,t}^{TRANS,+}-P_{\bar{r},r,t}^{TRANS,-})-P_{r,s,t}^{WIND,-}\\&=p_{r,t}^{BID\_WIND}-P_{r,t}^{DAY\_AHEAD,WIND\_SHED}\\&-p_{r,s,t}^{ACTUAL\_WIND}+\sum_{\bar{r},r}(P_{r,\bar{r},t}^{TRANS,-}-P_{r,\bar{r},t}^{TRANS,+})\\&\qquad\qquad\forall r\in R,\ \forall s\in S,\ \forall t\in T\end{aligned}\tag{3}$$

The balance on the heat market is given as the heat production on CHP plants, heat boilers, heat pumps and unloading of heat storages equal to the loading of heat storages and an exogenously given heat demand divided with the heat distribution loss for each area (4). The GAMS code for having price flexible heat demand is implemented but due to lack of data this possibility is not used presently.

QHEQ:
$$\sum_{i\in I_a^{HEAT}}Q_{\mathrm{i,s},t}=\sum_{i\in I^{HEATSOTRAGE}}W_{i,s,t}^{HEAT}+d_{a,t}^{HEAT}\Big/\big(1-DISLOSS\_H\big)\qquad\forall a\in A,\ \forall s\in S,\ \forall t\in T\tag{4}$$

The representation of each individual district heating grid existing in reality as a separate heat area in the model is not feasible due to calculation time and data restrictions. Therefore the district heating grids are aggregated in the model. When aggregating two CHP plants with different marginal production costs, that in reality produce in separate heat grids, the risk is that the CHP plant with the cheapest production costs produce relatively to much and the expensive CHP plant produce to little due to the aggregation. For Germany this problem has been reduced by using minimum bounds on the heat production from different CHP plants (5). The minimum bounds are calculated with a separate methodology describing the heat generating units in Germany (Weber & Barth 2004).

QGHEATMIN:
$$Q_{\mathrm{i,s},t}\geq H_{i,t}^{MIN\_BOUND}\qquad\forall i\in I^{HEAT},\ \forall s\in S,\ \forall t\in T\tag{5}$$

9.2.2 Demand for ancillary and non-spinning secondary reserves

The day-ahead market for ancillary services (i.e. primary reserves) is described by demand restrictions for up (6) and down regulation (7). The exogenously given demand for up regulation can be supplied either by increased power production of the power producing unit groups or by reduced loading of electricity storages and use of heat pumps, whereas the exogenously given demand for down regulation can be meet by decreasing the power production or by increasing the loading of electricity storages and use of heat pumps. The equation (8) ensures that only spinning unit groups can provide primary reserves. Currently this equation is replaced by using the subset I^{SPIN} in equation (6) und (7).

QANCPOSEQ:
$$\sum_{i\in I_r^{ELEC}} P_{i,t}^{ANC,+} + \sum_{i\in I^{ELECSTORAGE}\cup I^{HEATPUMP}} W_{i,t}^{ANC,+} \geq d_{r,t}^{ANC,UP} \qquad \forall r \in R,\ \forall t \in T \tag{6}$$

QANCNEGEQ:
$$\sum_{i\in I_r^{ELEC}} P_{i,t}^{ANC,-} + \sum_{i\in I^{ELECSTORAGE}\cup I^{HEATPUMP}} W_{i,t}^{ANC,-} \geq d_{r,t}^{ANC,DOWN} \qquad \forall r \in R,\ \forall t \in T \tag{7}$$

QANC0:
$$\left(\frac{1}{p_i^{MIN\_PROD}} - 1\right) \cdot P_{i,s,t} \geq \sum_t P_{i,t}^{ANC,+} \qquad \forall i \in I^{SPIN} \forall r \in R, \forall s \in S, \forall t \in T \tag{8}$$

The market for non-spinning secondary reserves (minute reserves) is described by demand restriction for up regulation (9). The exogenously given demand for up regulation in a region can be supplied either by increased power production of the power producing unit groups, by reduced loading of electricity storages as well as use of heat pumps or can be imported from another region, which requires reservation of transmission capacity. The total demand for positive secondary reserve in a given time period and state is met partly by the variables in (9) and partly by reservation of online capacity using the up regulation variables in (3) for providing up regulation in the case of the expected wind power production being higher than the wind power forecast in a given state. Therefore the demand for secondary reserve in (9) is reduced in the case that the actual wind power production is lower than expected.

QNONSP_ANCPOSEQ:

$$\begin{aligned}
&\sum_{i\in I_r^{ELEC}} P_{i,t}^{NONSP,ANC,+} + \sum_{i\in I^{ELECSTORAGE}\cup I^{HEATPUMP}} W_{i,t}^{NONSP,ANC,+} \\
&+\sum_{r} (1 - XLOSS) \cdot P_{r,\bar{r},s,t}^{TRANS,NONSP,ANC,+} \\
&\geq d_{r,s,t}^{NONSP,ANC,UP} \\
&-\max\left\{0, p_{r,t}^{EXPECTED\_WIND} - p_{r,s,t}^{ACTUAL\_WIND}\right\} \\
&+\sum_{\bar{r}} (1 - XLOSS) \cdot P_{\bar{r},r,s,t}^{TRANS,NONSP,ANC,+} \\
&\qquad \forall r \in R, \forall t \in T, \forall s \in S
\end{aligned} \tag{9}$$

9.2.3 Capacity restrictions

The capacity restrictions for the unit groups generating electricity are defined in the following equations for maximum and minimum electric power output. The realised power production, i.e. the sum of the production committed to the day-ahead market and the regulation of the production sold at the intraday market, plus the contribution to the ancillary and non-spinning secondary reserve have to be lower than the available capacity equal to the installed capacity times the availability factor (10). The availability factor is equal to 1 minus the outage factor:

QGCAPELEC1:

$$P_{i,s,t} + P_{i,t}^{ANC,+} + P_{i,s,t}^{NONSP,ANC,+} \quad \leq \quad p_{i,t}^{GKDERATE}\, p_i^{MAX\_PROD} \qquad (10)$$
$$\forall i \in I^{ELEC},\ \forall s \in S, \forall t \in T$$

For unit groups with start-up costs, i.e. thermal unit groups, this is later restricted to being lower than $P_{i,s,t}^{ONLINE}$, the capacity online for the unit group i at time step t.

To ensure that the power which is committed to the day-ahead market does not become unreasonable big, equation (11) has to be considered:

QGCAPELEC3: $$P_{i,t}^{DAY\_AHEAD} \leq p_i^{GKDERATE}\, p_i^{MAX\_PROD} \qquad (11)$$
$$\forall i \in I^{ELEC}, t \in T$$

$P_{i,s,t}^{ONLINE}$ is an additional variable introduced in order to describe start-up costs, reduced part-load efficiency and the restrictions for minimum shut down and minimum operation times as well as lead times in a linear programming model. In the typical unit commitment models the restrictions for e. g. the minimum operation time and minimum down time include integer variables. However, this is hardly feasible for a model representing a national market. Therefore (Weber & Barth 2004) proposes an approximation to model the restrictions in a linear way, which makes it necessary to introduce this additional decision variable $P_{i,s,t}^{ONLINE}$. The idea is illustrated in Figure 3.

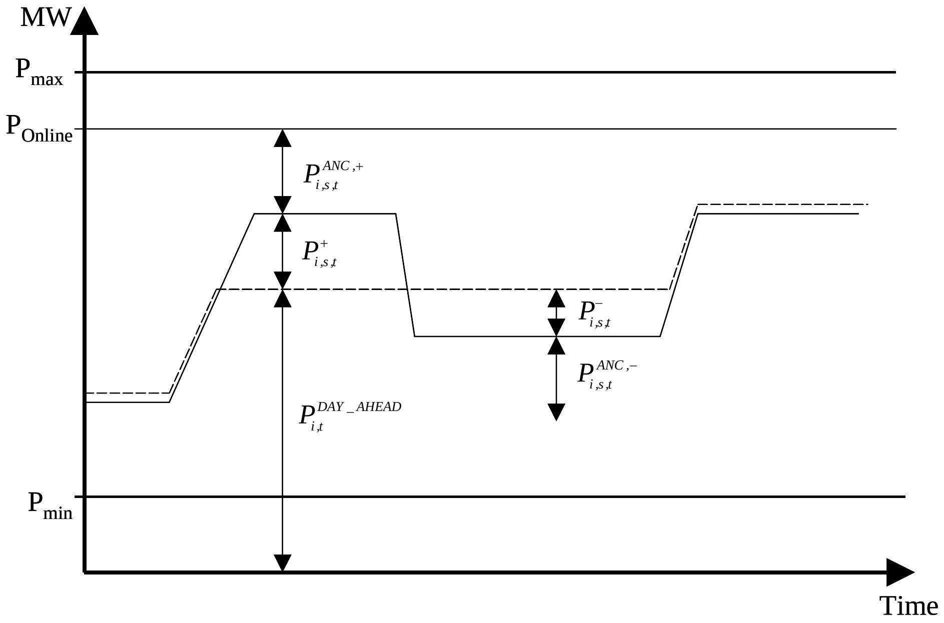

Figure 3: Illustration of the contribution of a power generating turbine to the different markets.

Compared to using integer variables the main difference with the linear approximation is that we can bring any amount of additional capacity online, as long as the amount is smaller than the available capacity, e.g. bring 0.1 MW online if it is optimal to do so. This is not as problematic as it sounds in a model where individual power plants anyhow are aggregated into unit groups. The capacity online multiplied with the minimum output factor $p_i^{MIN\_PROD}$ forms a lower bound to the possible power output (12):

QGONLCND2: $$P_{i,s,t} - P_{i,t}^{ANC,-} \geq p_i^{MIN\_PROD} \cdot P_{i,s,t}^{ONLINE} \quad \forall i \in I_R^{ELEC},\ \forall s \in S, \forall t \in T \qquad (12)$$

The value of the decision variable $P_{i,s,t}^{ONLINE}$ itself has to be lower than the maximum capacity of the unit group i including the availability factor $p_i^{GKDERATE}$ (13):

QGONLCAP: $$P_{i,s,t}^{ONLINE} \leq p_i^{GKDERATE} p_i^{MAX\_PROD} \quad \forall i \in I^{ELEC}, s \in S, t \in T \qquad (13)$$

CHP unit groups are distinguished into extraction condensing unit groups and backpressure unit groups. The used PQ-charts (electric power - thermal power charts) show in a simplified version the possible operation modes of the unit groups representing the possible combinations of electric and thermal power produced. In Figure 4 examples of PQ-charts for the two different types of CHP turbines included in the model are shown. Hence, additional equations to match these technical restrictions are required.

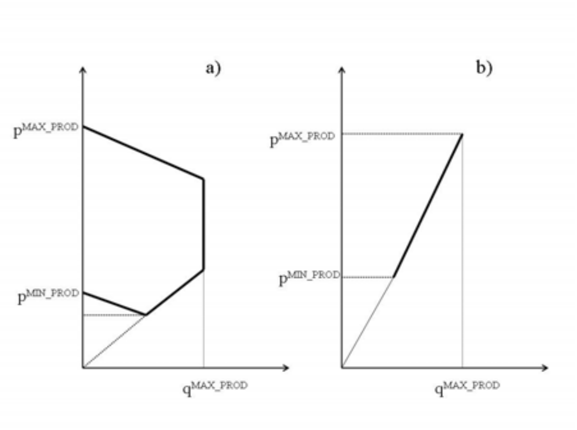

Figure 4: Simplified PQ-chart for a) extraction-condensing turbines and b) back pressure turbines

For extraction turbines the output of heat and power is restricted by the following equations representing the upper line (14), the lower line of the PQ-chart (15) and the line according to the heat ratio δ_i^{CB} (16), respectively:

QGEXTRACT1: $$P_{i,s,t} + P_{i,t}^{ANC,+} + P_{i,s,t}^{NONSP,ANC,+} \leq P_{i,s,t}^{ONLINE} - \gamma_i \cdot Q_{i,s,t} \quad \forall i \in I^{EXTRACTION}, \forall s \in S, \forall t \in T \qquad (14)$$

QGEXTRACT2: $$P_{i,s,t} - P_{i,t}^{ANC,-} \geq p_i^{MIN\_PROD} \cdot P_{i,s,t}^{ONLINE} - \gamma_i \cdot Q_{i,s,t} \quad \forall i \in I^{EXTRACTION}, \forall s \in S, \forall t \in T \qquad (15)$$

QGCBGEXT:
$$P_{i,s,t} - P^{ANC,-}_{i,t} \geq \delta^{CB}_{i} \cdot Q_{i,s,t} \qquad \forall i \in I^{EXTRACTION}, \forall s \in S, \forall t \in T \tag{16}$$

Where γ_i corresponds to the electric power reduction due to heat production. For gas-turbines that are used as CHP units, γ_i is set to zero.

Backpressure turbines produce heat and power with the constant heat ratio δ^{CB}_{i} . Hence, the following equations for backpressure turbines are used accordingly (17), (18), (19):

QGBACKPR1:
$$P_{i,s,t} + P^{ANC,+}_{i,t} + P^{NONSP,ANC,+}_{i,s,t} \leq P^{ONLINE}_{i,s,t} \qquad \forall i \in I^{BACKPRESSURE}, \forall s \in S, \forall t \in T \tag{17}$$

QGBACKPR2:
$$P_{i,s,t} - P^{ANC,-}_{i,t} \geq p^{MIN\_PROD}_{i} \cdot P^{ONLINE}_{i,s,t} \qquad \forall i \in I^{BACKPRESSURE}, \forall s \in S, \forall t \in T \tag{18}$$

QGCBGBPR:
$$P_{i,s,t} = \delta^{CB}_{i} Q_{i,s,t} \qquad \forall i \in I^{BACKPRESSURE}, \forall s \in S, \forall t \in T \tag{19}$$

Equation *QGONLCND1* is the same equation as *QGBACKPR1* except that it applies for condensing type of thermal units.

Generally, the maximum heat production of the heat generating unit groups I^{HEAT} has to be restricted to the heat generation capacity (20):

QGCAPHEAT:
$$Q_{i,s,t} \leq q^{MAX\_PROD}_{i} \qquad \forall i \in I^{HEAT}, \forall s \in S, \forall t \in T \tag{20}$$

As the model is defined as a multi-region model, the capacity restrictions of the transmission lines are defined in (21).

QXK:
$$\begin{aligned} & P^{TRANS,DAY-AHEAD}_{r,\bar{r},t} + P^{TRANS,+}_{r,\bar{r},s,t} \\ & -P^{TRANS,-}_{r,\bar{r},s,t} + P^{TRANS,NONSP,ANC,+}_{r,\bar{r},s,t} \leq l^{TRANS,MAX}_{r,\bar{r}} \\ & \qquad \forall r,\bar{r} \in R,\ \forall t \in T, \forall s \in S \end{aligned} \tag{21}$$

To ensure that the transmission planned at the day-ahead market does not exceed the available transmission capacity, equation (22) has to be applied:

QXK2:
$$P^{TRANS,DAY-AHEAD}_{r,\bar{r},t} \leq l^{TRANS,MAX}_{r,\bar{r}} \qquad \forall r,\bar{r} \in R,\ \forall t \in T, \forall s \in S \tag{22}$$

9.2.4 Restrictions for down regulation

The model has a possibility for allowing wind power shedding on the day-ahead market. In this case the amount of possible wind shedding has to be lower than the wind power production that has been expected at the hour when the day-ahead is cleared (i.e. at 12 o'clock) (23):

QWINDSHED:
$$P^{DAY\_AHEAD,WINDSHED}_{r,t} \leq p^{BID\_WIND}_{r,t} \qquad \forall r \in R, \forall t \in T \tag{23}$$

Realised wind power shedding is also included in the model. Here the shedding of the wind power production has to be smaller than the actual wind power production:

$$QGCAPELEC2\textbf{:}\quad P^{WIND,-}_{r,s,t} \quad \le \quad p^{WIND}_{r,s,t} \qquad\qquad \forall r \in R,\, \forall s \in S, \forall t \in T \qquad (24)$$

The down regulation for electricity producing unit groups can not be larger than the committed production (25):

$$QGNEGDEV:\quad P^{-}_{i,s,t} + P^{ANC,-}_{i,s,t} \le \quad P^{DAY\_AHEAD}_{i,t} + P^{+}_{i,s,t} \qquad (25)$$
$$\forall i \in I^{ELEC}\ , s \in S,\, \forall t \in T$$

And also the down regulation by the transmission lines has to be lower than the planned transmission (26):

$$QXNEGDEV:\quad P^{TRANS,-}_{r,\bar{r},s,t} \quad \le \quad P^{TRANS,DAY-AHEAD}_{r,\bar{r},t} \qquad (26)$$
$$\forall r, \bar{r} \in R,\, s \in S,\, \forall t \in T$$

9.2.5 Fuel consumption

Equation (27) determines the fuel used by conventional power plants for producing power and heat. In order to avoid that unit groups are always kept online and to account for that the efficiency at part load is lower than at full load, the fuel consumption of the started capacity $P^{ONLINE}_{i,s,t}$ is included:

QGFUELUSE:

$$\sum_r F_{s,t} = e_i \cdot P^{ONLINE}_{i \in I^{USING\_FUEL},s,t} + f_i \cdot (\, P_{i \in I^{USING\_FUEL},s,t} + \gamma_i Q_{i \in I^{CHP},s,t} + Q_{i \in I^{HEATONLY},s,t}\,) \qquad (27)$$
$$\forall i \in I^{USING\_FUEL}, \forall s \in S, \forall t \in T$$

Where e_i is the fuel consumption parameter for the capacity online, f_i the fuel consumption parameter when unit group i produces power according to the full load efficiency. γ_i stands for the electric power reduction due to heat production. Accordingly the amount of heat production multiplied with the factor γ_i corresponds to the increased fuel consumption caused by heat production of extraction CHP plants. γ_i is set to 1 for backpressure plants, because f_i for backpressure plants is defined as the ratio between the sum of the power and heat production divided with the fuel consumption.

9.2.6 Started capacity

Additional costs due to power plant start-ups influence considerably the unit commitment decisions of plant operators. Therefore the started capacity has to be defined with the following equation (28):

$$QGONLSTART:\quad P^{STARTUP}_{i,s,t} \ge P^{ONLINE}_{i,s,t} - P^{ONLINE}_{i,s,t-1} \qquad (28)$$
$$\forall i \in I^{ONLINE}, \forall s \in S,\ \forall t \in T$$

9.2.7 Minimum operation and shut down times, lead-times

Like power plant start-ups, minimum operation times and minimum shut down times influence the unit commitment decisions of plant operators. The typical formulation of the minimum operation times restrictions says, that a unit group can be shut down only if it was online during the last $t_i^{MIN\_OP}$ time steps. In the linear approximation the requirement is, that the reduction in the capacity online of unit group i between time step t and time step t-1 cannot exceed the capacity online during the last $t_i^{MIN\_OP}$ time steps (29). These time steps correspond to the minimum operation hours of the corresponding power plant.

$$\textit{QGONLOP:} \quad P_{i,s,t-1}^{ONLINE} - P_{i,s,t}^{ONLINE} \le P_{i,s,\tau}^{ONLINE} \quad \forall \tau \text{ with } t - t_i^{MIN\_OP} \le \tau \le t-1 \quad \forall i \in I^{ELEC},\, s \in S,\, \forall t \in [t_i^{MIN\_OP},...,T^{OPTIM\_PERIOD}] \tag{29}$$

Conversely the maximum start-up capacity is limited to be the capacity shut-down during the last $t_i^{MIN\_SD}$ time steps (30).

$$\textit{QGONLSD:} \quad P_{i,s,t}^{ONLINE} - P_{i,s,t-1}^{ONLINE} \le P_{i,s,\tau}^{ONLINE} - P_{i,s,t}^{ONLINE} \quad \forall \tau \text{ with } t - t_i^{MIN\_SD} \le \tau \le t-1 \quad \forall i \in I^{ELEC},\, s \in S,\, \forall t \in [t_i^{MIN\_SD},...,T^{OPTIM\_PERIOD}] \tag{30}$$

In the current version of the model, the equations for the minimum operation and shut down times are neglected. Instead, the unit commitment is restricted by the use of lead-times that describe the needed time to change the capacity online of a unit group i. Accordingly the model is only able to react on different wind power scenarios after the leadtime of the unit group i has passed (31):

$$\textit{QLEADTIME:} \quad P_{i,s,\tau}^{ONLINE} = P_{i,s',\tau}^{ONLINE} \quad \forall i \in I,\, s \in S, s' \in S\ \tau \text{ with } t \le \tau < t + t_i^{LEADTIME} \tag{31}$$

To save calculation time and to take into account that some units produce at a constant level without taking wind power production fluctuations into account, e.g. power producing waste incineration plants, the following equation do the same as *QLEADTIME*, but for all time steps:

$$\textit{QGONLMEDIU:} \quad P_{i,s,t}^{ONLINE} = P_{i,s',t}^{ONLINE} \quad \forall i \in I^{INFLEXIBLE},\, s \in S,\, s' \in S, t \in T \tag{32}$$

Furthermore the possibility of having some power plants that only change their online capacity according to planned revisions is included by the following equations:

$$\textit{QGONLSLOW:} \quad P_{i,s,t}^{ONLINE} = p_i^{GKDERATE}\, p_i^{MAX\_PROD} \quad \forall i \in I^{CONSTANT\_CAPACITY},\, s \in S,\, t \in T \tag{33}$$

9.2.8 Ramp rates

Equation (34) restricts the increase of the power production of an unit group i. As all unit groups are expected to increase their power production from minimal to maximal capacity within an hour, this equation is not used in the model.

QGRAMP:

$$P_{i,s,t} - P_{i,s,t-1} \le P_{i,s,t}^{ONLINE} \cdot RAMPRATE \qquad \forall\, i \in I^{RAMP},\, s \in S,\, t \in T \tag{34}$$

9.2.9 Electric heat pumps

Electric heat pumps are described by the equation (35). Thereby the variables describing the consumed electricity production $W_{i,s,t}$ and the full load efficiency $\eta_i^{FULLLOAD}$ are used:

QGGETOH:

$$W_{i,s,t} = Q_{i,s,t} \big/ \eta_i^{FULLLOAD} \qquad \forall i \in I^{HEATPUMPS}, s \in S, t \in T \tag{35}$$

9.2.10 Hydro power

The equations for the hydro power plants with reservoirs are summarized in the following: Equation (36) restricts the maximum reservoir capacity, whereas (37) represents the minimum reservoir capacity. Equation (38) determines the actual content of the reservoir capacity by taking into account the precedent content, the power production and the natural water inflow.

QHYRSSEQ:

$$V_{i,s,t}^{HYDRO} \le \sum_i v_i^{HYDRO,MAX} \qquad \forall i \in I^{HYDRO}, s \in S, t \in T \tag{36}$$

QHYRSMAXCON:

$$V_{i,s,t}^{HYDRO} \ge \sum_i v_i^{HYDRO\,,MIN} \qquad \forall i \in I^{HYDRO}, s \in S, t \in T \tag{37}$$

QHYRSMINCON:

$$V_{i,s,t}^{HYDRO} = V_{i,s,t-1}^{HYDRO} - P_{i,s,t} + i_{i,t}^{INFLOW} \qquad \forall\, i \in I^{HYDRO},\, s \in S,\, t \in T \tag{38}$$

The equation (39) ensures that the sum of power production by hydro storage and run-of-river power plants is lower than the installed capacity:

QHYRSMAXPROD:

$$\begin{aligned} &\sum_{i \in I^{HYDRO}} P_{i,s,t} + \sum_{i \in I^{HYDRO}} P_{i,s,t}^{NONSP,ANC,+} + \sum_t \sum_{i \in I^{HYDRO}} P_{i,s,t}^{ANC,+} + i_{i,t}^{RUNRIVER} \\ &\le \sum_{i \in I^{HYDRO}} p_i^{MAX\_PROD} + \sum_{i \in I^{RUNRIVER}} p_i^{MAX\_PROD} \\ &\qquad\qquad \forall\, s \in S, t \in T \end{aligned} \tag{39}$$

9.2.11 Electricity and heat storages

For electricity storages like pumped hydro storages, the following equations are used: The electricity storage dynamic equation (40) determines the actual storage content by taking into account the precedent content, the used capacity for loading the electricity storage multiplied with the load loss and the power production:

QESTOVOLT:

$$V_{i,s,t}^{ELECSTORAGE} = \sum_{s} V_{i,s,t-1}^{ELECSTORAGE} + LOADLOSS \cdot W_{i,s,t} - P_{i,s,t} \qquad (40)$$

$$\forall i \in I^{ELECSTORAGE}, s \in S, t \in T$$

The capacity for the loading process of electricity storages is restricted by equation (41) that also considers electric heat pumps. The sum of the loading process plus the contribution of electricity storages to the up regulating at the ancillary and non-spinning secondary market has to be lower or equal than the loading capacity plus the heat capacity of the electric heat pumps multiplied with the outage factor:

QESTOLOADC:

$$W_{i,s,t} + \sum_{t} W_{i,s,t}^{ANC,-} + W_{i,s,t}^{NONSP,ANC,-}$$

$$\leq (w_i^{MAX} + q_i^{MAX\_PROD} / \eta_i^{FULLLOAD}) \cdot (1 - p_i^{GKDERATE}) \qquad (41)$$

$$\forall i \in I^{ELECSTORAGE} \cup I^{HEATPUMP}, s \in S, t \in T$$

To ensure that the planned capacity consumption for the loading of electricity storages and for the use of heat pumps at the day-ahead market does not become unreasonable big, equation (42) has to be considered:

QGCAPELEC4:

$$W_{i,t}^{DAY\_AHEAD} \leq (w_i^{MAX} + q_i^{MAX\_PROD} / \eta_i^{FULLLOAD}) \cdot (1 - p_i^{GKDERATE}) \qquad (42)$$

$$\forall i \in I^{ELECSTORAGE} \cup I^{HEATPUMP}, t \in T$$

The maximal contribution of electric storages to the down regulation is determined by equation (43) conversely. Thereby the equation also considers electric heat pumps:

QESTOLOADA:

$$W_{i,s,t}^{-} + W_{i,s,t}^{NONSP,ANC,+} + \sum_{t} W_{i,s,t}^{ANC,+} \leq W_{i,t}^{DAY-AHEAD} + W_{i,s,t}^{+} \qquad (43)$$

$$\forall i \in I^{ELECSTORAGE} \cup I^{HEATPUMP}, s \in S, t \in T$$

The maximum electricity storage content is restricted by equation (44):

QESTOMAXCO: $V_{i,s,t}^{ELECSTORAGE} \leq v_i^{ELECSTORAGE,MAX}$

$$\forall i \in I^{ELECSTORAGE}, s \in S, t \in T \qquad (44)$$

The equations for heat storages show a similar structure. The heat storage dynamic equation (45), the restriction for the maximal loading process of heat storages (46) and the maximum heat storage content (47) are defined as follows:

QHSTOVOLT:

$$V_{i,s,t}^{STORAGE} = \sum_{s} V_{i,s,t-1}^{STORAGE} \cdot LOADLOSS + W_{i,s,t}^{HEAT} - Q_{i,s,t} \quad \forall i \in I^{HEATSTORAGE}, s \in S, t \in T \qquad (45)$$

QHSTOLOADC:

$$W_{i,s,t}^{HEAT} \le w_i^{MAX} \quad \forall i \in I^{HEATSTORAGE}, s \in S, t \in T \qquad (46)$$

QHSTOMAXCO:

$$V_{i,s,t}^{STORAGE} \le v_i^{HEATSTORAGE,MAX} \quad \forall i \in I^{HEATSTORAGE}, s \in S, t \in T \qquad (47)$$

10 Rolling planning

The inclusion of uncertainty about the wind power production in the optimisation model is considered by using a scenario tree. The scenario tree represents wind power production forecasts with different forecast horizons corresponding to each hour in the optimisation period. For a given forecast horizon the scenarios of wind power production forecasts in the scenario tree are represented as a number of wind power production outcomes with associated probabilities, i.e. as a distribution of future wind power production levels. The methodology to generate this scenario tree is described in deliverable 6.2 (d).

As it is not possible to cover the whole simulated time period with only one single scenario tree, the model is formulated by introducing a multi-stage recursion using rolling planning. In stochastic multi-stage linear recourse models, there exist two types of decisions: “root” decisions that have to be taken before the outcome of uncertain events (stochastic parameters) is known and hence must be robust towards the different possible outcomes of the uncertain events, and “recourse decisions” that can be taken after the outcome of uncertain events is resolved. With these “recourse decisions” actions can be started which might possibly revise the first decisions. In the case of a power system with wind power, the power generators have to decide on the amount of electricity they want to sell at the day-ahead market before the precise wind power production is known (root decision). In most European countries this decision has to be taken at least 12-36 hours before the delivery period. And as the wind power prediction is not very accurate, recourse actions in the form of up or down regulations of power production is necessary in most cases.

In general, new information arrives on a continuous basis and provides updated information about wind power production and forecasts, the operational status of other production and storage units, the operational status of the transmission and distribution grid, heat and electricity demand as well as updated information about day-ahead market and regulating power market prices. Thus, an hourly basis for updating information would be most adequate. However, stochastic optimisation models quickly become intractable, since the total number of scenarios has a double exponential dependency in the sense that a model with $k+1$ stages, m stochastic parameters, and n scenarios for each parameter (at each stage) leads to a scenario tree with a total of $s = n^{mk}$ scenarios (assuming that scenario reduction techniques is not applied). It is therefore necessary to simplify the information arrival and decision structure in the stochastic model.

In the current version of the model a three stage model is implemented. The model steps forward in time using rolling planning with a 3 hour step. For each time step new wind power production forecasts (i.e. a new scenario tree) that consider the change in forecast horizons are used. This decision structure is illustrated in Figure 5 showing the scenario tree for four planning periods. For each planning period a three-stage, stochastic optimisation problem is solved having a deterministic first stage covering 3 hours, a stochastic second stage with five scenarios covering 3 hours, and a stochastic third stage with 10 scenarios covering a variable number of hours according to the rolling planning period in question. In the planning period 1 the amount of power sold or bought from the day-ahead market for the next day is determined. In the subsequent replanning periods the variables for the amounts of power sold or bought on the day-ahead market are fixed to the values found in planning period 1, such that the obligations on the day-ahead market are taken into account when the optimisation of the intra-day trading takes place.

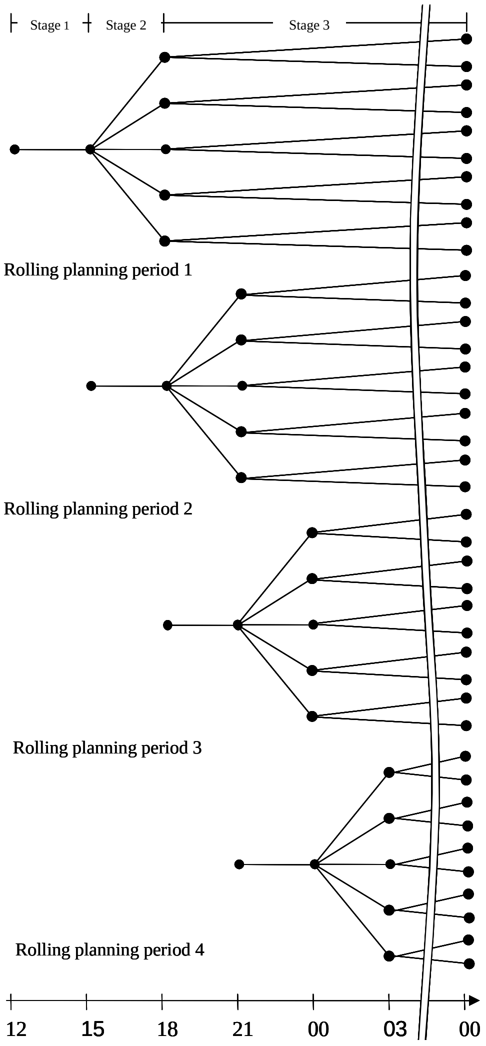

Figure 5: Illustration of the rolling planning and the decision structure in each planning period within half a day.

10.1 Looping structure

As mentioned above a looping structure is implemented in the JMM that steps forward in time with three hour steps. A daily cycle consists of eight planning loops with the optimization period in the first loop covering the period from 12.00 the first day until midnight the second day (see Figure 5). In this planning loop the day-ahead market for the second day is optimized such that the amounts bought and sold on this market are determined. The market for primary reserves delivered the second day is optimized such that it is determined which unit groups that provide negative and positive primary reserves the second day. The intra-day market in the hours 12.00-15.00 is cleared such that the realized amounts of consumption, production and transmission in the power system in these hours are determined. Furthermore the dispatch of power plants is planned for the rest of the hours in the optimization period taking the distribution of wind power forecasts into account. The optimization period in the next loop starts at 15.00 and ends at the same time as the first planning loop, i.e. midnight of the second day. In this planning loop the intraday market for the first three hours (period 15.00-18.00) is cleared taking the obligations on the day-ahead market and the obligations concerning primary reserves into account. Furthermore the dispatch of power plants in the rest of the hours in the optimization period is replanned taking the new wind power forecasts into account. The same procedure goes for the next six planning loops, and then the daily cycle starts again.

The start-up times of unit groups imply that when optimizing a planning loop, it should not be allowed to increase the online capacity of a unit group in the first lead time hours of the planning loop, because it takes lead time hours from we decide to increase the capacity of a unit group until the capacity is brought online. Therefore before solving a planning loop, the online capacity of a unit group in the first lead time hours of the planning loop is fixed to the online capacity found in the previous planning loop for the same hours.

Table 11 gives an overview of the steps involved in the looping structure.

Table 11: Structure of GAMS code in main model file (Wilmar1_12.gms).

Before first planning loop:

1. Define external sets and parameters and import data to these
2. Define internal sets and parameters
3. Define variables
4. Define equations
5. Define model (select equations to be included in the present model)
6. Transfer yearly data (capacities of production, storage and transmission technologies, fuel prices) from external to internal parameters
7. Transfer start data (filling degree of hydro reservoirs, heat and power storages)
8. Transfer start hydro reservoir level to the long-term model

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Within each planning loop:

Before solving the model:

1. Set values for scenario tree (start and end time of each stage …)
2. Transfer hourly data (nominal electricity demand, heat demand ….) from external to internal parameters.

3. Import water values from LTM corresponding to the present filling degree in hydro reservoirs.
4. Transfer scenario dependant data (wind power production forecasts, demand for secondary reserve) from external to internal parameters.
5. Update shadow values for having capacity online and having energy stored in heat storages or electricity storages in the end of the optimisation period.

Furthermore if the day-ahead market and the market for primary reserves are optimised in this planning loop (the planning loop starting in hour 12.00) the following takes place before solving the model:

6. Call long-term model that calculates water values.
7. Remove fixing of variables for the day-ahead market (production, electricity storage loading, transmission, price flexible electricity demand) i.e. these variables are unfixed for day 2 in the optimization period.
8. Remove fixing of primary reserve variables.

Solve model.

After having solved the model:

9. For planning loops started in hour 12.00: Save realised shadow values for having capacity online and having energy stored in heat or electricity storages at midnight on the first day.
10. For the first lead time hours of the next planning loop fix the online capacity of unit groups to the online capacity found in this planning loop for the same hours.
11. Transfer hydro reservoir levels to long-term model.
12. Fix the amounts of primary reserve provided by unit groups in the next planning loop to the values found in this planning loop. If the next planning loop starts at 12.00: unfix the primary reserve variables for the second day of the optimisation period.
13. For planning loop started at 12.00 and for day 2 in the optimization period covering the day-ahead market: Calculate the realised electricity demand by adding/subtracting the activated price flexible electricity demand from the nominal demand.
14. Fix the electricity demand, the day-ahead market variables (production, transmission and loading of storages) in the next planning period to the values found in this planning loop. As we loop 3 hours between each planning loop this involves shifting the time series of these variables three hours in time.

10.2 Calculation of shadow values

The optimization period in the JMM is at most 36 hours long due to calculation time restrictions. Therefore an economic value has to be allocated to having energy stored in heat storages and electricity storages and having capacity online in the end of each optimization period. If an economic value was not allocated and there was energy stored in storages in the start of the optimization period, the JMM would consider no cost of using this stored energy and subsequently use too much stored electricity in the optimization period in question compared to using it in later optimization periods.

The basic idea when using shadow values is to take the value of having energy stored or capacity online at midnight (as the planning loops always ends at midnight) in a previous planning loop, which is the marginal (shadow) value of the balance equations of storages (QESTOVOLT, QHSTOVOLT) and capacity started up (QGONLSTART), and use it as the economic values in the present planning loop. As the shadow values are dependant on the present status of the power system, the operating situation in the previous planning loop should resemble the operating status in the present planning loop as much as possible. As indicator of the status of the power system the electricity demand minus the fluctuating production (unregulated hydro and wind power), i.e. the demand for production that can be dispatched, is determined. The algorithm is the following:

- After having solved the JMM in the first planning loop of the simulation period (which always starts at 12.00):
    - For hour 23.00-00.00 in day 1: Save the marginal values QESTOVOLT.M(a,i,s), QHSTOVOLT.M(a,i,s) and QGONLSTART.M(a,i,s).
    - For hour 23.00-00.00 in day 1: Save the value A_1(r,s) = Elec_Demand(r) – RunRiver(r) – WindForecast(r,s)
- Before solving the model in the second planning loop:
    - Calculate the value A_2(r,s) = ElecDemand(r) – RunRiver(r) – WindForecast(r,s) for the hour 23.00-00.00 in day 2.
    - For each node in the second planning loop find the node N in the first planning loop where the squared distance between A_1(r,N) and A_2(r,s) is the smallest. Use the marginal values found in the first planning loop for node N when solving the second planning loop.
- When solving the model in the third to ninth planning loop:
    - Use the procedure explained above for the second planning loop. Notice that it is still the marginal values found in the first planning loop that are used.
- After a day cycle the procedure starts from the beginning, i.e. after having solved the JMM in the ninth planning loop a new set of shadow values are saved and used in the next eigth planning loops.

As the electricity demand changes a lot between working days and weekend days, it is necessary to distinguish between working days and weekend days in the usage of shadow values. Therefore the usage of shadow values is a bit more complicated in the JMM than outlined above. Planning loops where the optimization period ends before a working day, i.e. midnight at Monday, Tuesday, Wednesday, Thursday and Sunday use shadow values found in the previous working day. Planning loops ending at Friday and Saturday use shadow values found in the previous weekend day, i.e. in the case of planning loops ending Friday, shadow values found in the planning loop starting at 12.00 the previous Sunday are used.

11 Specification of the model used

Possibilities for making different choices concerning the JMM to run can be made. They are the following:

- Choice between stochastic or deterministic version of the JMM. This choice is included in the user shell. People not using the user shell can choose between deterministic and stochastic JMM in file *“base\model\choice.gms“*.
- Number of planning loops to run (LOOPRUNS) and start time of the simulation period (STARTLOOP). Choice done in user shell or alternatively in file *“base\model\choice.gms“*.
- The equations included in the model are specified in file *“base\model\Wilmar1_12.gms“* by listing their names in the list WILMARBASE1. By excluding an equation name from this list, this equation will not be part of the JMM run. This can e.g. be used to exclude start-up and shut-down times from the JMM as is presently done.
- Four binary parameters are defined in the beginning of file *“base\model\Wilmar1_12.gms“*. These parameters allow easy choice between the following possibilities:
    - IHLP_FLEXIBLE_DEF_YES = 1 ⇒ price flexible electricity demand is active in the JMM.
    - IVWINDSHEDDING_DAYAHEAD_YES = 1 ⇒ a variable containing wind shedding on the day-ahead market is active (VWINDSHEDDING_DAY_AHEAD). Thereby it is allowed in the JMM to bid less than the expected wind power production into the day-ahead market if this is optimal.
    - ITRANSMISSION_NONSP__YES = 1 ⇒ exchange of positive secondary (minute) reserve between regions is possible, which includes the possibility of reserving transmission capacity for exchanging minute reserves.
    - ICONSTANTWIND_YES = 1 ⇒ the JMM is run with a constant wind power production equal to the average weekly wind power production. Used only in connection with the deterministic JMM.

11.1 Deterministic version of the model

The deterministic JMM is a JMM run with a scenario tree that only consists of three nodes (one in each stage) with the wind power production in the nodes being the realised wind power production, i.e. the forecast errors are zero. So running the deterministic JMM is equal to assuming perfect foresight for the wind power production. The selection of the time series for wind power production and secondary positive reserve for the deterministic JMM is done in the Wilmar Planning tool input database.

The total need for secondary, positive reserve in the stochastic JMM is found by adding the distribution of wind power production forecast errors with the distribution of outages of power plants. These two distributions are seen as stochastically independent. In stead of having a distribution of power plant outages, the model considers the secondary positive reserve values required by the TSOs in each country, which is found by applying a N-1 criteria, as expressing some percentile in the outage distribution, that the TSOs have agreed upon as expressing a reasonable level of system security. As there are no wind power forecast errors in the deterministic JMM, the total need for secondary positive reserve in the deterministic JMM is only given by the values required to cover power plant outages.

Except for using a scenario tree with fewer nodes and calculating the total need for positive secondary reserve a little different, the deterministic JMM is equal to the stochastic JMM.

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Appendix A : Sets in the model

Set	Defined on Sets	Description	Source
A_AId	AAA,AId	Connection between Areas and ID of Areas.	O Set A_AId.inc
AAA		All areas.	O SET A.inc
AAAIER3H	AAA	General heat areas.	O SET AIER3H.inc
AId		ID of Areas.	O Set AId.inc
BASEDAY		Days in simulation.	O Set BASEDATE.inc
BASETIME		Hourly time step, format Yyyy-Mm-Dd-Hh.	O Set BASETIME.inc
BASETIME_WEEK	BASETIME,WEEKS	Connection between BASETIME og WEEKS.	O SET BaseTime_WWW.inc
C		Countries in the simulation.	O SET C.inc
CaseId		ID of run case.	O Set CaseId.inc
CaseName		Name of run case.	O Set CaseName.inc
CCCRRR	C,RRR	Assignment of regions to countries.	O SET CR.inc
DAY		Consists of DAY1 og DAY2.	(sets.inc)
DAY_TTT_00_02	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_03_05	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_06_08	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_09_11	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_12_14	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_15_17	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_18_20	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DAY_TTT_21_23	DAY,T	Mapping days to time according to rolling planning horizont.	(sets.inc)
DEF		Steps in elastic electricity demand.	(sets.inc)
DEF_D	DEF	Downwards steps in elastic electricity demand.	O Set DEF_D.inc
DEF_U	DEF	Upwards steps in elastic electricity demand.	O Set DEF_U.inc
DHF		Steps in elastic heat demand.	(sets.inc)
DHF_D	DHF	Downwards steps in elastic heat demand.	(sets.inc)
DHF_U	DHF	Upwards steps in elastic heat demand.	(sets.inc)
DYN_DAY_AHEAD	T	Consists of T13 - T36.	(sets_det_3hours.inc and sets_stoch.inc)
DYN_DAY_AHEAD_FIRST_SOLVE	T	Consists of T01 - T36.	(sets_det_3hours.inc and sets_stoch.inc)
FFF		Fuels.	O SET FFF.inc

Set	**Defined on Sets**	**Description**	**Source**
FUELDATASET		Characteristics of fuels.	(sets.inc)
G		Generation technologies in the simulation.	O SET G.inc
G_GId	G,GId	Connection between Name and ID of generation technologies.	O Set G_GId.inc
GALWAYSRUNNING	G	Technologies with available capacity being always online.	O Set GALWAYSRUNNING.inc
GDATASET		Generation technology data.	(sets.inc)
GId		ID of generation technologies.	O Set GId.inc
GINFLEXIBLE	G	Technologies with online capacity being independent of the wind power scenario.	O SET GINFLEXIBLE.inc
GONLINE	G	Technologies with costs associated with bringing and having capacity online.	O SET GONLINE.inc
GSPINNING	G	Units providing primary (spinning) reserves.	O SET GSPINNING.inc
GSTARTSET		Generation technology data.	(sets.inc)
HYRSFILLING		Levels in hydro reservoirs.	(sets.inc)
IA	AAA	Areas in the simulation.	Given in program code.
IAALIAS		Aliased with IA.	Aliased with IA.
IAGK_Y	AAA,G	Area and Technology with positive capacity for current simulation year.	Given in program code.
IAHYDRO	AAA	Areas containing hydropower with reservoirs.	Given in program code.
IAIER3H	AAA	General heat areas in the simulation, heat demand determined by IER3 heat model.	Given in program code.
ICA	C,AAA	Assignment of areas to countries.	Given in program code.
IDT	DAY,T	Day time mapping.	Given in program code.
IENDTIME	T	Last timestep of each optimisation period, as rolling planning periods always end at the end of the day.	Given in program code.
IENDTIME_SHADOWPRICE	T	Timestep when shadowprice is determined.	Given in program code.
IEXPORT_Y	RRR,RRR	Lines with positive transmission capacity.	Given in program code.
IGALIAS		Aliased with G.	Aliased with G.
IGALLWAYSRUNNING	G	Same as GALWAYSRUNNING.	Given in program code.
IGBACKPR	G	Back pressure technologies.	Given in program code.
IGCON_HYRES_ELSTO	G	Condensing technologies and hydropower with reservoir technologies and electricity storage.	Given in program code.
IGCONDENSING	G	Condensing technologies.	Given in program code.
IGELEC	G	Technologies generating electricity.	Given in program code.
IGELECANDHEAT	G	Technologies generating electricity and heat.	Given in program code.
IGELECFLUCTUATION	G	Technologies that cannot be scheduled e.g. wind, solar, hydro run-of-river.	Given in program code.
IGELECNOFLUC_NOONLYDAYAHEAD	G	Unit groups that can be scheduled and which are not part of IGONLYDAYAHEAD.	Given in program code.
IGELECNOFLUCTUATION	G	Technologies that can be scheduled.	Given in program code.

Set	**Defined on Sets**	**Description**	**Source**
IGELECNOPARTLOAD	G	Technologies where partload efficiency is same as full load efficiency.	Given in program code.
IGELECONLY	G	Technologies generating electricity only.	Given in program code.
IGELECPARTLOAD	G	Technologies where partload efficiency is different from fullload efficiency.	Given in program code.
IGELECSTORAGE	G	Electricity storage technologies.	Given in program code.
IGELECTHERMAL	G	Thermal electricity producing units (condensing + extraction + backpressure).	Given in program code.
IGESTORAGE_HEATPUMP	G	Electricity storage, electrical boilers and heat pumps.	Given in program code.
IGEXTRACTION	G	Extraction technologies.	Given in program code.
IGHEAT	G	Technologies generating heat.	Given in program code.
IGHEAT_NO_STORAGE	G	All technologies delivering heat except heat storages.	Given in program code.
IGHEATBOILER	G	Heat-only boilers.	Given in program code.
IGHEATONLY	G	All technologies generating heat-only.	Given in program code.
IGHEATPUMP	G	Electric boilers and heatpumps.	Given in program code.
IGHEATSTORAGE	G	Heat storage technologies.	Given in program code.
IGHYDRO	G	Hydropower.	Given in program code.
IGHYDRORES	G	Hydropower with reservoir.	Given in program code.
IGINFLEXIBLE	G	Same as GINFLEXIBLE.	Given in program code.
IGLEADTIME	G	Plants that have lead time >1.	Given in program code.
IGLEADTIME_NOALWAYS	G	Plants that have lead time >1 and is not always online.	Given in program code.
IGMINOPERATION	G	Plants that have minimum operation time >1.	Given in program code.
IGNONSPINNING	G	Technologies providing non-spinning reserve.	Given in program code.
IGONL_CONDENSING	G	Condensing technoliges with part load efficiency different from maximum efficiency.	Given in program code.
IGONLINE	G	Same as GONLINE.	Given in program code.
IGONLINE_NOALLWAYS	G	Plants that are part of IGONLINE and is not always online.	Given in program code.
IGONLYDAYAHEAD	G	Unit groups offering all their production capacity to the day-ahead market, and only the capacity not sold on day-ahead on the intraday market.	Given in program code.
IGRAMP	G	Plants that have ramp rate above 1 hour (i.e. GDRAMP <1).	Given in program code.
IGRUNOFRIVER	G	Hydropower run-of-river (no reservoir).	Given in program code.
IGSOLAR	G	Solar power technologies.	Given in program code.
IGSPINNING	G	Same as GSPINNING.	Given in program code.
IGSTORAGE	G	Electricity and heat storage technologies.	Given in program code.
IGUSINGFUEL	G	Technologies using fuel (not included water, solar).	Given in program code.
IGWIND	G	Wind power technologies.	Given in program code.

Set	Defined on Sets	Description	Source
IGWIND_SOLAR_ROV	G	Wind, solar and run-of river power technologies.	Given in program code.
INFEASIBLE_SET	AAA,G,BASETIME	Set for checking if bound < capacity : IER3.	Given in program code.
INFOTIME	BASETIME	Start time of one rolling planning run.	O Set INFOTIME.inc
INODEALIAS		Aliased with NODE.	Aliased with NODE.
INODEALIAS2		Aliased with NODE.	Aliased with NODE.
INT	NODE,T	Node time mapping.	Given in program code.
INT_WITH_HIST	NODE,TTT	Node time mapping - also for historical timesteps.	Given in program code.
IPLUSMINUS		Violation of equation.	Given in program code.
IR	RRR	Regions in the simulation.	Given in program code.
IRALIAS		Aliased with RRR.	Aliased with RRR.
IRE		Aliased with RRR.	Aliased with RRR.
IRI		Aliased with RRR.	Aliased with RRR.
IRRRE		Aliased with RRR.	Aliased with RRR.
IRRRI		Aliased with RRR.	Aliased with RRR.
IT_SPOTPERIOD	T	Timesteps for spot market optimisation.	Given in program code.
ITALIAS		Aliased with T.	Aliased with T.
ITALIAS_WITH_HIST		Aliased with T_WITH_HIST.	Aliased with T_WITH_HIST.
ITALIAS2		Aliased with T.	Aliased with T.
ITMPGBACKPR	G	Back pressure technologies.	Given in program code.
ITMPGCONDENSING	G	Condensing technologies.	Given in program code.
ITMPGELECSTORAGE	G	Electricity storage technologies.	Given in program code.
ITMPGEXTRACTION	G	Extraction technologies.	Given in program code.
ITMPGHEATBOILER	G	Heat-only boilers.	Given in program code.
ITMPGHEATPUMP	G	Electric heaters or heatpumps.	Given in program code.
ITMPGHEATSTORAGE	G	Heat storage technologies.	Given in program code.
ITMPGHYDRORES	G	Hydropower with reservoir.	Given in program code.
ITMPGLEADTIME	G	Plants that have lead time >1.	Given in program code.
ITMPGMINOPERATION	G	Plants that have minimum operation time >1.	Given in program code.
ITMPGRAMP	G	Plants that have ramp rate above 1 hour (i.e. GDRAMP <1).	Given in program code.
ITMPGRUNOFRIVER	G	Hydropower run-of-river no reservoir.	Given in program code.
ITMPGSOLAR	G	Solar power technologies.	Given in program code.

Set	Defined on Sets	Description	Source
ITMPGWIND	G	Wind power technologies.	Given in program code.
MPOLSET		Emission and other policy data.	(sets.inc)
NNN		Nodes (NODE_000 to NODE_100).	(sets_det_3hours.inc and sets_stoch.inc)
NODE	NNN	Nodes in simulation (NODE_000, NODE_001 and NODE_006).	(sets_det_3hours.inc, NODE_6hours.inc and NODE_3hours.inc)
NODE_TTT_00_02	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_03_05	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_06_08	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_09_11	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_12_14	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_15_17	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_18_20	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_21_23	NODE,T	Links between nodes and time steps.	(sets_det_3hours.inc and NODE_TTT_3hours.inc)
NODE_TTT_HIST	NODE,TTT	Links between nodes and time steps.	(sets_det_3hours.inc and sets_stoch.inc)
PREDECESSOR	NNN,NNN	Set defining the predecessor node to each node.	(sets_det_3hours.inc, PREDECESSOR_6hours.inc and PREDECESSOR_3hours.inc)
R_RId	RRR,RId	Connection between Regions and ID of Regions.	O Set R_RId.inc
RId		ID of Regions.	O Set RId.inc
RRR		All regions.	O SET R.inc
RRRAAA	RRR,AAA	Assignment of areas to regions.	O SET RA.inc
SCEN	SSS	Scenarios in simulation.	(sets_det_3hours.inc, SCEN_6hours.inc and SCEN_3hours.inc)
SCEN_NODE	SSS,NNN	Nodes of each scenario.	(sets_det_3hours.inc, SCEN_NODE_6hours.inc and SCEN_NODE_3hours.inc)
SSS		Scenarios.	(sets_det_3hours.inc and sets_stoch.inc)
STAGE		Stages of the tree (STAGE1, STAGE2 and STAGE3).	(sets_det_3hours.inc and sets_stoch.inc)
STAGE_NODE		Link between nodes and time steps.	(sets_det_3hours.inc, STAGE_NODE_6hours.inc and STAGE_NODE_3hours.inc)
T	TTT	Consists of T00 - T36.	(sets.inc)

Set	Defined on Sets	Description	Source
T_WITH_HIST	TTT	Consists of TM01 - TM24 and T00 - T36.	(sets.inc)
TTT		Consists of TM01 - TM24 and T00 - T36.	(sets.inc)
WEEKS		Week numbers for one year.	(sets.inc)
Y	YYY	Years in the simulation.	O SET Y.inc
YYY		All years.	(sets.inc)

Appendix B : Parameters in the model

Parameter	Defined on SETs	Description	Unit	Source
BASE_DE_ANCNEG_VAR_D	RRR,BASEDAY	Demand for negative spinning reserve.	MW	O Parameter BASE_DE_ANC_NEG_VAR_D.inc
BASE_DE_ANCPOS_VAR_D	RRR,BASEDAY	Demand for positive spinning reserve.	MW	O Parameter BASE_DE_ANC_POS_VAR_D.inc
BASE_DE_VAR_T	RRR,BASETIME	Electricity demand in a region in absolute, scaled values (hourly time series).	MW	O Parameter BASE_DE_VAR_T.inc
BASE_DEMAND_NONSPIN_ANCPOS	INFOTIME,RRR,NNN,TTT	Demand for positive secondary (minute) reserve demand (hourly values).	MW	O Parameter BASE_DEMAND_NONSPIN_ANCPOS.inc
BASE_DEMAND_NONSPIN_ANCPOS_N_1	RRR	Demand for positive secondary (minute) reserve demand due to N-1 criteria (outages). Used in deterministic JMM (hourly time series).	MW	O Parameter BASE_DEMAND_NONSPIN_ANCPOS_N_1.inc
BASE_DH_VAR_T	AAA,BASETIME	Hourly heat demand in an area in absolute, scaled values. The heat areas without hourly heat demand data get the hourly variation in heat demand from DK_W_Rural.	MW	O Parameter BASE_DH_VAR_T 1.inc and O Parameter BASE_DH_VAR_T 2.inc
BASE_GKDERATE_VAR_T	AAA,GGG,BASETIME	Availability representing planned and unplanned outages (hourly time series).	Ratio	O Parameter GKDERATE.inc
BASE_HEATGEN_LOWBOUND_VAR_T	AAA,G,BASETIME	Lower bound for heat producing units (hourly time series). Only used for CHP plants in Germany.	MW	O Parameter BASE_IER3LOWERBOUND_VAR_T.inc
BASE_INFLOWHYDRORES_VAR_T	RRR,BASETIME	Controllable inflow to hydro reservoirs (hourly time series).	MW	O Parameter BASE_INFLOWHYDRORES_VAR_T.inc
BASE_PROB_REACHNODE	INFOTIME,NNN	Probability of Node NNN in the scenario tree starting at time INFOTIME.	Ratio	O Parameter PROBREACHNODE.inc and O Parameter PROBREACHNODE Deterministic.inc
BASE_RUNRIVER_VAR_T	RRR,BASETIME	Hydro generation from run-of-river (hourly time series).	MW	O Parameter BASE_RUNRIVER_VAR_T.inc
BASE_SOLAR_VAR_T	RRR,BASETIME	Solar power generation (hourly time series).	MW	O Parameter BASE_SOLAR_VAR_T.inc
BASE_WEEKDAY_VAR_INFOTIME	INFOTIME	Weekday of the InfoTime. InfoTime is the time that the rolling planning is started. 1 stands for Monday, 2 for Tuesday,..., 7 for Sunday.		O Parameter INFOTIME_WEEKDAY.inc
BASE_WIND_VAR_Det	BASETIME,RRR	Deterministic version of the wind power scenario tree. Realised wind power production equal to root node values in the scenario tree (hourly time series).	MW	O Parameter BASE_WIND_VAR Det3.inc
BASE_WIND_VAR_NT	INFOTIME,RRR,NNN,TTT	Stochastic version of the wind power scenario tree. Forecasted wind power production (hourly values).	MW	O Parameter BASE_WIND_VAR_NT.inc
BASE_X3FX_VAR_T	RRR,BASETIME	Fixed exchange with third countries. Positive value means that power flows to the third region (hourly time series).	MW	O Parameter BASE_X3FX_VAR_T.inc
CONVERT_KG_PER_GJ_T_PER_MWH		Factor used to convert kg/GJ to ton/MWh.		Given in program code.
DEF_STEPS_PRICE	RRR,DEF	Absolute price of step in price elastic demand curve.	EUR2002/MWh	O Parameter

Parameter	Defined on SETs	Description	Unit	Source
				DEF_STEPS_PRICE.inc
DEF_STEPS_QUANT	RRR,DEF	Quantity of step in elastic demand curve.	MW	O Parameter DEF_STEPS_QUANT.inc
DEFP_BASE	RRR	Annual average consumer price of electricity (including taxes) in the base year. It is used as nominal value for calculations in relation to elastic demands.	EUR2002/MWh	O Parameter DEFP_BASE.inc
DHF_STEPS_PRICE	AAA,DHF	Price of each step in the heat demand curve.	EUR2002/MWh	O Parameter DHF_STEPS_PRICE.inc
DHF_STEPS_QUANT	AAA,DHF	Quantity of each step in the heat demand curve.	MW	O Parameter DHF_STEPS_QUANT.inc
DHFP_BASE	AAA	Annual average consumer price of heat (including taxes) in the base year. It is used as nominal value for calculations in relation to elastic demands.	EUR2002/MWh	O Parameter DHFP_BASE.inc
DISCOST_E	RRR	Cost of electricity distribution, given relative to end consumption.	EUR2002/MWh	O Parameter DISCOST_E1.inc
DISCOST_H	AAA	Cost of heat distribution, given relative to end consumption.	EUR2002/MWh	O Parameter DISCOST_H.inc
DISLOSS_E	RRR	Loss in electricity distribution, as a fraction of electricity consumed.	Ratio	O Parameter DISLOSS_E.inc
DISLOSS_H	AAA	Loss in heat distribution, as a fraction of heat consumed.	Ratio	O Parameter DISLOSS_H.inc
DURATION_STAGE	STAGE	Number of timesteps for each stage of the tree.	hours	(DURATION_STAGE_6hours.inc and DURATION_STAGE_3hours.inc)
ELEC_SUBSIDY	CCC,FFF	Subsidy on electricity produced from biomass or waste.	EUR2002/MWh	O Parameter ELEC_SUBSIDY.inc
EndTime		Time when Gams run ends.		Given in program code.
Epsilon		Small number to take care of numerical instabilities.		Given in program code.
ERRORCOUNT		Number of errors in the model run.		(print_file_definition.inc)
FDATA	FFF,FUELDATASET	Information about emission characteristics of fuels. SO_2 and CO_2.	kg/GJ	O Parameter FDATA.inc
FUELPRICE	YYY,AAA,FFF	Fuel prices.	EUR2002/MWh	Given in program code.
FUELPRICE_PER_GJ	YYY,AAA,FFF	Fuel price for areas with own fuel price scenarios.	EUR2002/GJ	O PARAMETER FUELPRICE_GJ.inc and O PARAMETER FUELPRICE_GJ 2.inc
GDATA	AAA,GGG,GDATASET	Characteristics of technologies.	Various	O PARAMETER GDATA.inc and O PARAMETER GDATA 1.inc
GKFX_CHARGINGSTORAGE	YYY,AAA,GGG	Capacity for the charging process of storages (pumping process of pumped hydro storage).	MW	O Parameter GKFX_CHARGINGSTORAGE.inc
GKFX_CONTENTSTORAGE	YYY,AAA,GGG	Maximum energy capacity of the storage.	MWh	O Parameter GKFX_CONTENTSTORAGE.inc

Parameter	Defined on SETs	Description	Unit	Source
GKFXELEC	YYY,AAA,GGG	Maximum electricity production.	MW	O Parameter GKFXELEC.inc
GKFXHEAT	YYY,AAA,GGG	Maximum heat production.	MW	O Parameter GKFXHEAT.inc
GKMAX_CONTENTHYDRORES	YYY,AAA,GGG	Upper bound on hydro reservoir filling.	MWh	O Parameter GKMAX_CONTENTHYDRORES.inc
GKMIN_CONTENTHYDRORES	YYY,AAA,GGG	Lower bound on hydro reservoir filling.	MWh	O Parameter GKMIN_CONTENTHYDRORES.inc
GSTARTVALUEDATA	AAA,GGG,GSTARTSET	Start Value for shut down time (GSSDTIME) and hydro reservoir filling (GSCONTENTHYDRORES).	Various	O Parameter GSTARTVALUEDATA.inc
HELPVAR		Help Parameter.		Given in program code.
HELPVAR1		Help Parameter.		Given in program code.
HELPVAR2		Help Parameter.		Given in program code.
HELPVAR3		Help Parameter.		Given in program code.
HELPVAR6	RRR,TTT	Help Parameter.		Given in program code.
HELPVARWP5	AAA,GGG,FFF	Help Parameter used when printing out results to the WP5 models.		Given in program code.
HELPVARWP5_2	AAA,GGG	Help Parameter used when printing out results to the WP5 models.		Given in program code.
hour		End hour of Gams run.		Given in program code.
IBASEFINALTIME	STAGE	Real final time for optimisation (planning horizon).		Given in program code.
IBASESTARTTIME	STAGE	Real start time for special stage of the tree.		Given in program code.
IBID_DAYAHEADMARKET_YES		Binary parameter indicating if spotmarket is optimised.		Given in program code.
ICALC_SHADOWPRICE_YES		Binary parameter for calculation of shadow price.		Given in program code.
IDEF_STEPS_QUANT	RRR,DEF	Quantity of each step in the electricity demand curve.	MW	Given in program code.
IDEFLEXIBLEPRICE_T	RRR,DEF	Prices on elastic electricity demand steps.	EUR2002/MWh	Given in program code.
IDEMAND_ANCNEG	RRR,DAY	Demand for negative ancilliary reserve.	MW	Given in program code.
IDEMAND_ANCPOS	RRR,DAY	Demand for positive ancilliary reserve.	MW	Given in program code.
IDEMAND_NONSPIN_ANCNEG	RRR,TTT	Demand for negative secondary reserve (hourly values).	MW	Given in program code.
IDEMAND_NONSPIN_ANCPOS	RRR,NODE,TTT	Demand for positive secondary reserve (hourly values).	MW	Given in program code.
IDEMANDELEC	RRR,TTT	Electricity demand (hourly values).	MW	Given in program code.
IDEMANDHEAT	AAA,TTT	Heat demand (hourly values).	MW	Given in program code.
IDHF_STEPS_QUANT	AAA,DHF	Quantity of each step in the heat demand curve.	MW	Given in program code.
IDHFLEXIBLEPRICE_T	AAA,DHF	Prices on elastic heat demand steps.	EUR2002/MWh	Given in program code.
IDURATION_STAGE	STAGE	Number of hours at each stage - is changed for different rolling priods.	hours	Given in program code.
IFINALNODE	STAGE	Last node that belongs to stage.		Given in program code.

Parameter	**Defined on SETs**	**Description**	**Unit**	**Source**
IFINALTIME	STAGE	Model end time for stage of the tree.		Given in program code.
IFIXSPINNING_UNITS_YES		Binary parameter indicating those rolling planning periods, when demand is fixed.		Given in program code.
IFLEXIBLE_DEF_YES		Binary parameter for model with flexible electricity demand.		Given in program code.
IFLEXIBLE_DHF_YES		Binary parameter for model with flexible heat demand.		Given in program code.
IFUELPRICE_Y	AAA,FFF	Fuel price for current simulation year.	EUR2002/MWh	Given in program code.
IFUELUSAGE_SECTION	AAA,G	Parameters for consumption function of used fuel.	MWh_fuel /MW_CapOnline	Given in program code.
IFUELUSAGE_SLOPE	AAA,G	Parameters for consumption function of used fuel.	MWh_fuel /MWh_Prod	Given in program code.
IGELECCAPACITY_Y	AAA,G	Power production capacity.	MW	Given in program code.
IGHEATCAPACITY_Y	AAA,G	Heat production capacity.	MW	Given in program code.
IGHYDRORESCONTENTCAPACITY_Y	AAA,G	Max content of hydro storage.	MWh	Given in program code.
IGHYDRORESMINCONTENT_Y	AAA,G	Min content of hydro storage.	MWh	Given in program code.
IGKDERATE	AAA,G,TTT	Availability representing planned and unplanned outages (hourly values).	Ratio	Given in program code.
IGSTOCONTENTCAPACITY_Y	AAA,G	Max content of electricity storage.	MWh	Given in program code.
IGSTOLOADCAPACITY_Y	AAA,G	Charging capacity of electricity storage.	MW	Given in program code.
IHEATGEN_LOWBOUND_VAR_T	AAA,G,T	Lower bound for heat producing units (hourly values).	MW	Given in program code.
IHLP_ELECCAPACITY_IR	RRR	Power production capacity in region, reduced by transmission losses.	MW	Given in program code.
IHLP_FLEXIBLE_DEF_YES		Binary parameter for model with flexible electricity demand.		Given in program code.
IHLP_HEATCAPACITY_IA	AAA	Heat production capacity in area, reduced by distribution losses.	MW	Given in program code.
IHLPDEMANDLEVEL_WEEKDAY	RRR,NODE	Level of electricity demand, weekday.	MW	Given in program code.
IHLPDEMANDLEVEL_WEEKEND	RRR,NODE	Level of electricity demand, weekend.	MW	Given in program code.
IHLPDIST1		Find node with smallest difference in demand.		Given in program code.
IHLPDIST2		Find node with smallest difference in demand.		Given in program code.
IHLPGELECCAPACITY_IR	RRR	Power production capacity in region.	MW	Given in program code.
IHLPGHEATCAPACITY_IA	AAA	Heat production capacity in area.	MW	Given in program code.
IHLPORDNODE		Node where difference in demand is smallest.		Given in program code.
IHLPSDPONLINE_WEEKDAY	AAA,G,NODE	Shadow price for unit being online, weekday.	Euro2002/MWh	Given in program code.
IHLPSDPONLINE_WEEKEND	AAA,G,NODE	Shadow price for unit being online, weekend.	Euro2002/MWh	Given in program code.
IHLPSDPSTORAGE_WEEKDAY	AAA,G,NODE	Shadow price for storage content, weekday.	Euro2002/MWh	Given in program code.
IHLPSDPSTORAGE_WEEKEND	AAA,G,NODE	Shadow price for storage content, weekend.	Euro2002/MWh	Given in program code.
IHYDROINFLOW_T_Y	AAA,T	Inflow to the hydro reservoirs (hourly values).	MW	Given in program code.

Parameter	Defined on SETs	Description	Unit	Source
IINFLOWHYDRORES_VAR_T	RRR,TTT	Inflow to the hydro reservoirs (hourly values).	MW	Given in program code.
INO_HOURS	DAY	Number of hours of rest of day.	hours	Given in program code.
INO_HOURS_OPT_PERIOD		Number of hours of optimisation period.	hours	Given in program code.
INO_NODES_AT_STAGE	STAGE	Number of nodes on each stage.		Given in program code.
INO_SOLVE		Number of runs.		Given in program code.
IPENALTY		Penalty on violation of equations.		Given in program code.
IPROBLEM_INFEASIBLE		Binary parameter for infeasibility.		Given in program code.
IPROBREACHNODE	NODE	Probabilty to reach this node.	Ratio	Given in program code.
IRESFILLWSTART	RRR	Hydro reservoir filling at the beginning of a planning loop (share).	Ratio	Given in program code.
IRUNRIVER_T_Y	AAA,T	Run of river distributed on areas (hourly values).	MW	Given in program code.
IRUNRIVER_VAR_T	RRR,TTT	Run-of-river production (hourly values).	MW	Given in program code.
ISDP_HYDRORES	RRR,TTT	Price profil for hydroreservoirs.	Euro2002/MWh	Given in program code.
ISDP_ONLINE	AAA,G,NODE	Shadow price for unit being online.	Euro2002/MWh	Given in program code.
ISDP_STORAGE	AAA,G,NODE	Shadow price for storage content.	Euro2002/MWh	Given in program code.
ISOLAR_VAR_T	RRR,TTT	Solar generation (hourly values).	MW	Given in program code.
ISTARTNODE	STAGE	First node that belongs to the stage.		Given in program code.
ISTARTTIME	STAGE	Model start time for stage of the tree.		Given in program code.
ISTATUSMOD		For saving the solution status of the model.		Given in program code.
ISTATUSSOLV		For the solution status.		Given in program code.
ITRANSMISSION_INTRADAY__YES		Binary parameter for model with transmission scheduled on both the intraday and day-ahead market.		Given in program code.
ITRANSMISSION_NONSP__YES		Binary parameter for transmission of non-spinning secondary reserve.		Given in program code.
IUPDATE_SHADOWPRICE_YES		Binary parameter for update shadow prices.		Given in program code.
IVWINDSHEDDING_DAYAHEAD_YES		Binary parameter for model with wind shedding on the day-ahead market.		Given in program code.
IWILMAR		WILMAR version.		Given in program code.
IWIND_AVG_IR	RRR,T	Expected average production from wind power forecasted at INFOTIME (hourly values).	MW	Given in program code.
IWIND_BID_IR	RRR,T	Expected average production from wind power forecasted at 12.00 for the next day (hourly values).	MW	Given in program code.
IWIND_REALISED_IR	RRR,NODE,T	Wind power production forecast (hourly values).	MW	Given in program code.
IX3COUNTRY_T_Y	RRR,T	Fixed exchange with third countries (hourly values).	MW	Given in program code.
IXCAPACITY_Y	IRRRE,IRRRI	Transmission capacity between regions.	MW	Given in program code.
LAG_TIME_BIDDING		Bidding for the lag time.	hours	(parameter_stoch.inc)

Parameter	Defined on SETs	Description	Unit	Source
LOOPRUNS		Number of loops included in one run (deterministic JMM).		Choice.gms
M_POL	MPOLSET,CCC	Emissions policy data. Tax on SO_2 and CO_2.	EUR2002/ton CO_2 or ton SO_2	O Parameter M_POL.inc
minute		End minute of Gams run.		Given in program code.
NO_HOURS_OVERLAP		Number of hours for which rolling planning is executed.	hours	Given in program code.
NO_OF_SUCCESSORS	STAGE	Number of sons for each node, except leave node.		(NO_OF_SUCCESSORS_6hours.inc and NO_OF_SUCCESSORS_3hours.inc)
NO_ROLL_PERIODS_WITHIN_DAY		Number of rolling planning periods within a day.		Given in program code.
OCASEID		Identification of the WILMAR model.		Given in program code.
second		End second of Gams run.		Given in program code.
STARTLOOP		The number of infotimes that are skipped before solving the model.		Choice.gms
TAX_DE	CCC	Consumers' tax on electricity consumption.	EUR2002/MWh	O Parameter TAX_DE.inc
TAX_DH	CCC	Consumers' tax on heat consumption.	EUR2002/MWh	O Parameter TAX_DH.inc
TAX_HEATPUMP	CCC	Heat pump consumers' tax on electricity consumption.	EUR2002/MWh	O Parameter TAX_HEATPUMP.inc
vobj_out	RRR,TTT	Production and transmission costs.	EUR2002	Given in program code.
WARNINGCOUNT		Number of warnings in the model run.		(print_file_definition.inc)
WV1REG	WEEKS,HYRSFILLING	Water values calculated by LTM (one-reservoir model).	Euro2002/MWh	WV1REG.gdx
WVINFEAS		Value used when hydropower reached the minimum reservoir level.	Euro2002/MWh	(sets.inc)
XCAPACITY	RRR,RRR	Intital electrical transmission capacities between pairs of regions. The electrical transmission capacity is the capacity disregarding a possible loss.	MW	O Parameter XCAPACITY.inc
XCOST	IRRRE,IRRRI	Electrical transmission cost between pairs of regions. Applies to the electricity entering the transmission line.	EUR2002/MW	O Parameter XCOST.inc
XLOSS	RRR,RRR	Loss in transmission expressed as a fraction of the power entering the transmission line.	Ratio	O Parameter XLOSS.inc

Appendix C : Decision Variables in the model

Variable	Defined on SETs	Description	Unit
VCONTENTHYDRORES_NT	AAA,NODE,T	Content of hydro reservoir.	MWh
VCONTENTSTORAGE_NT	AAA,G,NODE,T	Content of electricity storage.	MWh
VDEMANDELECFLEXIBLE_T	RRR,T,DEF	Flexible electricity demands.	MW
VDEMANDHEATFLEXIBLE_NT	AAA,NODE,T,DHF	Flexible heat demands.	MW
VGE_ANCNEG	AAA,G,DAY	Capacity reserved for providing negative primary reserve.	MW
VGE_ANCPOS	AAA,G,DAY	Capacity reserved for providing positive primary reserve.	MW
VGE_CONSUMED_ANCNEG	AAA,G,DAY	Reservation of increased loading capacity of electricity storage or heat pump for providing negative primary reserve.	MW
VGE_CONSUMED_ANCPOS	AAA,G,DAY	Reservation of decreased loading capacity of electricity storage or heat pump for providing positive primary reserve.	MW
VGE_CONSUMED_NONSP_ANCNEG	AAA,G,NODE,T	Reservation of increased loading capacity of electricity storage or heat pump for providing negative non-spinning reserve.	MW
VGE_CONSUMED_NONSP_ANCPOS	AAA,G,NODE,T	Reservation of decreased loading capacity of electricity storage or heat pump for providing positive non-spinning reserve.	MW
VGE_NONSPIN_ANCPOS	AAA,GGG,NODE,T	Contribution to negative non-spinning reserve.	MW
VGELEC_CONSUMED_DNEG_NT	AAA,G,NODE,T	Decreased loading of electricity storage or heat pump.	MW
VGELEC_CONSUMED_DPOS_NT	AAA,G,NODE,T	Increased loading of electricity storage or heat pump.	MW
VGELEC_CONSUMED_T	AAA,G,T	Loading of electricity storage or heat pump fixed on day-ahead market.	MW
VGELEC_DNEG_NT	AAA,G,NODE,T	Down regulation.	MW
VGELEC_DPOS_NT	AAA,G,NODE,T	Up regulation.	MW
VGELEC_T	AAA,G,T	Electricity generation.	MW
VGFUELUSAGE_NT	AAA,G,NODE,T	Fuel usage.	MW
VGHEAT_CONSUMED_NT	AAA,G,NODE,T	Loading of heat storage.	MW
VGHEAT_NT	AAA,G,NODE,T	Heat generation.	MW
VGONLINE_NT	AAA,G,NODE,TTT	Capacity online.	MW
VGSTARTUP_NT	AAA,G,NODE,T	Capacity started up from time step T-1 to T.	MW
VHYDROSPILLAGE	AAA,NODE,T	Spillage of hydropower due to overflow in reservoirs.	MW
VOBJ		Objective function value.	EUR2002
VQDAYAHEAD	RRR,T,IPLUSMINUS	Feasibility of QEEQDAY.	MW
VQHEQ	AAA,NODE,T,IPLUSMINUS	Feasibility of QHEQ.	MW
VQINTRADAY	RRR,NODE,T,IPLUSMINUS	Feasibility of QEEQINT.	MW
VQNONSP_ANCPOSEQ	RRR,NODE,T,IPLUSMINUS	Feasibility of QANC_NONSP_POSEQ.	MW
VWINDSHEDDING_DAY_AHEAD	RRR,T	Wind shedding day-ahead.	MW

Variable	Defined on SETs	Description	Unit
VXE_NONSPIN_ANCPOS	IRRRE,IRRRI,NODE,T	Electricity export of positive non-spinning reserve.	MW
VXELEC_DNEG_NT	IRRRE,IRRRI,NODE,T	Electricity export of down regulation.	MW
VXELEC_DPOS_NT	IRRRE,IRRRI,NODE,T	Electricity export of up regulation.	MW
VXELEC_T	IRRRE,IRRRI,T	Electricity export from region IRRRE to IRRRI.	MW

Appendix D : Input data files, Set definitions

File	GAMS set	Type	Source table	Description
O Set CaseName.inc	CaseName	Case	Case Selected	Case name
O Set CaseId.inc	CaseId	Case	CaseId	Case ID
O Set DEF_D.inc	DEF_D (DEF)	Demand	Data RRR Steps Elastic Demand Curve Electricity	Elasticity step where Electricity=True and Down=True
O Set DEF_U.inc	DEF_U (DEF)	Demand	Data RRR Steps Elastic Demand Curve Electricity	Elasticity step where Electricity=True and Up=True
O Set DHF.inc	Not used	Demand	Base Elasticity Step	Elasticity step where Heat=True
O Set FFF.inc	FFF & F (FFF)	Fuel	Base Fuels	Fuel names
O Set A.inc	AAA	Geography	Base Areas	Areas
O Set AId.inc	AId	Geography	Base Areas	AreaId
O Set A_AId.inc	A_AId (AAA, AId)	Geography	Base Areas	Areas; AreaIds
O Set AIER3H.inc	AAAIER3H (AAA)	Geography	Base Areas	Areas where "Base Areas".IER3=True
O Set AURBH.inc	AAAURBANH(AAA)	Geography	Base Areas	Areas where "Base Areas".IER3=False
O Set R.inc	RRR	Geography	Base Regions	Regions
O Set RId.inc	RId	Geography	Base Regions	Region IDs
O Set R_RId.inc	R_RId (RRR, RId)	Geography	Base Regions	Regions; Region IDs
O Set RA.inc	RRRAAA (RRR, AAA)	Geography	Base Regions & Base Areas	Regions; Areas
O Set C.inc	CCC & C (CCC)	Geography	Base Countries	Countries
O Set CR.inc	CCCRRR (CCC, RRR)	Geography	Base Countries & Base Regions	Countries; Regions
O Set G.inc	GGG & G (GGG)	Technology	Base Unit Groups	Unit groups
O Set GId.inc	GId	Technology	Base Unit Groups	Unit group IDs
O Set G_GId.inc	G_GId (GGG, GId)	Technology	Base Unit Groups	Unit groups; Unit group IDs
O Set GALWAYSRUNNING.inc	GALWAYSRUNNING (GGG)	Technology	Base Unit Groups	Unit groups where IsAlwaysRunning=True
O Set GONLINE.inc	GONLINE (GGG)	Technology	Base Unit Groups	Unit groups where Vgonline=Yes
O Set GSPINNING.inc	GSPINNING (GGG)	Technology	Base Unit Groups	Unit groups where SpinningReserve=Yes
O Set GINFLEXIBLE.inc	GINFLEXIBLE (GGG)	Technology	Base Unit Groups	Unit groups where FlexibleToWind=No
O Set Y.inc	Y (YYY)	Time	Base Years	Year
O Set BASEDATE.inc	BASEDAY	Time	Base Date	Dates

File	GAMS set	Type	Source table	Description
O Set BASETIME.inc	BASETTT & BASETIME (BASETTT)	Time	Base Time	Hours
O Set WWW.inc	Not used	Time	LTM Base Date	Week numbers
O Set BaseTime_WWW.inc	BASETIME_WEEK (BASETIME, WEEKS)	Time	Base Time & LTM Base Time	Hours; Week numbers
O Set INFOTIME.inc	INFOTIME (BASETIME)	Time	Base Time	Info hours

Appendix E : Data input files, Parameters

File	Gams parameter	GAMS dependency	Description	Unit
O Parameter BASE_DE_ANC_NEG_VAR_D.inc	BASE_DE_ANCNEG_VAR_D	RRR, BASEDAY	Average value of negative spinning reserve demand.	MW
O Parameter BASE_DE_ANC_POS_VAR_D.inc	BASE_DE_ANCPOS_VAR_D	RRR, BASEDAY	Average value of positive spinning reserve demand.	MW
O Parameter BASE_DE_VAR_T.inc	BASE_DE_VAR_T	RRR, BASETIME	Hourly time series for electricity demand in a region in absolute, scaled values.	MW
O Parameter BASE_DEMAND_NONSPIN_ANCPOS.inc	BASE_DEMAND_NONSPIN_ANCPOS	INFOTIME, RRR, NNN, TTT	Demand for positive secondary (minute) reserve demand.	MW
O Parameter BASE_DEMAND_NONSPIN_ANCPOS_N_1.inc	BASE_DEMAND_NONSPIN_ANCPOS_N_1	RRR	Demand for positive secondary (minute) reserve demand caused by N-1 criteria (outages). Used in deterministic JMM.	MW
O Parameter BASE_DH_VAR_T 1.inc	BASE_DH_VAR_T	AAA, BASETIME	Hourly time series for the heat demand in an area in absolute, scaled values. Profile taken from DK_W_Rural	MW
O Parameter BASE_DH_VAR_T 2.inc	BASE_DH_VAR_T	AAA, BASETIME	Hourly time series for the heat demand in an area in absolute, scaled values for heat areas with own historical demand profile.	MW
O Parameter BASE_IER3LOWERBOUND_VAR_T.inc	BASE_HEATGEN_LOWBOUND_VAR_T	AAA, G, BASETIME	Hourly minimum heat production of a unit group.	MW
O Parameter BASE_INFLOWHYDRORES_VAR_T.inc	BASE_INFLOWHYDRORES_VAR_T	RRR, BASETIME	Hourly time series of controllable water inflow to the reservoirs.	MW
O Parameter BASE_RUNRIVER_VAR_T.inc	BASE_RUNRIVER_VAR_T	RRR, BASETIME	Hourly time series of hydro generation from hydro run-of-river generation technologies.	MW
O Parameter BASE_RUNRIVER_VAR_T 1.inc	BASE_RUNRIVER_VAR_T	RRR, BASETIME	Hourly time series of hydro generation from hydro run-of-river generation technologies.	MW
O Parameter BASE_SOLAR_VAR_T.inc	BASE_SOLAR_VAR_T	RRR, BASETIME	Hourly time series of solar power production.	MW
O Parameter BASE_WIND_VAR Det3.inc	BASE_WIND_VAR_Det	BASETIME, RRR	Deterministic version of the wind power scenario tree. Hourly time series of realised wind power production equal to root node values in the scenario tree.	MW
O Parameter BASE_WIND_VAR_NT.inc	BASE_WIND_VAR_NT	INFOTIME, RRR, NNN, TTT	Stochastic version of the wind power scenario tree. Hourly time series of forecasted wind power production.	MW
O Parameter BASE_X3FX_VAR_T.inc	BASE_X3FX_VAR_T	RRR, BASETIME	Hourly time series for fixed exchange with third regions. Positive value means that the power flows from R to ThirdRegion.	MW
O Parameter DEF_STEPS_PRICE.inc	DEF_STEPS_PRICE	RRR, DEF	Absolute price of step in price elastic demand curve	EUR2002
O Parameter DEF_STEPS_QUANT.inc	DEF_STEPS_QUANT	RRR, DEF	Quantity of step in elastic demand curve	MWh
O Parameter DEFP_BASE.inc	DEFP_BASE	RRR	Annual average consumer price of electricity (including taxes) in the base year. It is used as nominal value for calculations in relation to elastic demands.	EUR2002/MWh
O Parameter DHF_STEPS_PRICE.inc	DHF_STEPS_PRICE	AAA, DHF	Price of step relatively to DHFP_ Base in price elastic heat demand curve.	EUR2002/EUR2002
O Parameter DHF_STEPS_QUANT.inc	DHF_STEPS_QUANT	AAA, DHF	Quantity of step relatively to nominal demand in price elastic heat demand curve	MWh/MWh

File	Gams parameter	GAMS dependency	Description	Unit
O Parameter DHFP_BASE.inc	DHFP_BASE	AAA	Annual average consumer price of heat (including taxes) in the base year. It is used as nominal value for calculations in relation to elastic demands.	EUR2002/MWh
O Parameter DISCOST_E.inc	DISCOST_E	RRR	Cost of electricity distribution, given relative to end consumption.	EUR2002/MWh
O Parameter DISCOST_H.inc	DISCOST_H	AAA	Cost of heat distribution, given relative to end consumption.	EUR2002/MWh
O Parameter DISLOSS_E.inc	DISLOSS_E	RRR	Loss in electricity distribution, as a fraction of electricity consumed.	None
O Parameter DISLOSS_H.inc	DISLOSS_H	AAA	Loss in heat distribution, as a fraction of heat consumed.	None
O Parameter ELEC_SUBSIDY.inc	ELEC_SUBSIDY	CCC, FFF	Subsidy on electricity produced from biomass or waste.	EUR2002/MWh
O Parameter FDATA.inc	FDATA	FFF, FUELDATASET	Information about emission characteristics of fuels. SO$_2$ and CO$_2$.	kg/GJ
O Parameter FUELPRICE_GJ.inc	FUELPRICE_PER_GJ	YYY, AAA, FFF	Fuel price for areas with own fuel price scenarios.	EUR2002/GJ
O Parameter FUELPRICE_GJ 2.inc	FUELPRICE_PER_GJ	YYY, AAA, FFF	Fuel price for areas getting the fuel price scenario of DK_E_Rural	EUR2002/GJ
O Parameter GDATA.inc	GDATA	AAA, GGG, GDATASET	Data on production technologies :	
			GDCB Cb-value.	MWElec/MWHeat
			GDCV Cv-value.	MWElec/MWHeat
			GDFUEL Fuel type.	None
			GDFUELTAX Tax for fuels used in either heat and/or electricity production.	EUR2002/GJ
			GDFUELTAXRED Tax reduction for fuels used in either heat and/or electricity production. Applies only for Germany	None
			GDFULLLOAD Full load efficiency.	None
			GDLEADTIME Lead time.	h
			GDLOADLOSS Effiency of storage when loading.	None
			GDMINLOADFACTOR Minimum load factor.	None
			GDMINOPERATION Minimum operation time.	h
			GDMINSHUTDOWN Minimum shutdown time.	h
			GDOMVCOST Variable operating and maintenance costs.	EUR2002/MWh
			GDPARTLOAD Part load efficiency.	None
			GDSTARTUPCOST Variable start-up costs.	EUR2002/MW
			GDTYPE Generation type.	None
O Parameter GDATA 1.inc	GDATA	AAA, GGG, GDATASET	Data on production technologies :	

File	Gams parameter	GAMS dependency	Description	Unit
			GDDESO2 Degree of desulphuring.	None
			GDFE_SECTION Fuel efficiency : Section of line of fuel consumption function.	MWh_fuel /MW_CapOnline
			GDFE_SLOPE Fuel efficiency : Slope of line of fuel consumption function.	MWh_fuel /MWh_Prod
O Parameter GKDERATE.inc	BASE_GKDERATE_VAR_T	AAA, GGG, BASETIME	Horly time series for availability = 1 - FOR. Data only if < 1. FOR : Outage due to planned revisions.	None
O Parameter GKFX_CHARGINGSTORAGE.inc	GKFX_CHARGINGSTORAGE	YYY, AAA, GGG	Capacity for the charging process of storages (pumping process of pumped hydro storage).	MWh
O Parameter GKFX_CONTENTSTORAGE.inc	GKFX_CONTENTSTORAGE	YYY, AAA, GGG	Maximum energy capacity of the storage.	MWh
O Parameter GKFXELEC.inc	GKFXELEC	YYY, AAA, GGG	Maximum electricity production.	MW
O Parameter GKFXHEAT.inc	GKFXHEAT	YYY, AAA, GGG	Maximum heat production.	MW
O Parameter GKMAX_CONTENTHYDRORES.inc	GKMAX_CONTENTHYDRORES	YYY, AAA, GGG	Upper bound on hydro reservoir filling. Relative to total reservoir capacity.	MWh
O Parameter GKMIN_CONTENTHYDRORES.inc	GKMIN_CONTENTHYDRORES	YYY, AAA, GGG	Lower bound on hydro reservoir filling. Relative to total reservoir capacity.	MWh
O Parameter GSTARTVALUEDATA.inc	GSTARTVALUEDATA	AAA, GGG, GSTARTSET	Start Value for shut down time (GSSDTIME) and hydro reservoir filling (GSCONTENTHYDRORES).	h and MWh
O Parameter INFOTIME_WEEKDAY.inc	BASE_WEEKDAY_VAR_INFOTIME	INFOTIME	Weekday of the InfoTime. InfoTime is the time that the rolling planning is started. 1 stands for monday, 2 for tuesday,..., 7 for sunday.	None
O Parameter M_POL.inc	M_POL	MPOLSET, CCC	Emissions policy data. Tax on SO_2 and CO_2.	EUR2002/ton CO_2 or ton SO_2
O Parameter PROBREACHNODE.inc	BASE_PROB_REACHNODE	INFOTIME, NNN	Probability of Node NNN in the scenario tree starting at time INFOTIME	None
O Parameter PROBREACHNODE Deterministic.inc	BASE_PROB_REACHNODE	INFOTIME, NNN	Probability of root node in deterministic scenario tree starting at time INFOTIME. All values equal to 1.	None
O Parameter TAX_DE.inc	TAX_DE	CCC	Consumers' tax on electricity consumption.	EUR2002/MWh
O Parameter TAX_DH.inc	TAX_DH	CCC	Consumers' tax on heat consumption.	EUR2002/MWh
O Parameter TAX_HEATPUMP.inc	TAX_HEATPUMP	CCC	Heat pump consumers' tax on electricity consumption.	EUR2002/MWh
O Parameter XCAPACITY.inc	XCAPACITY	RRR, RRR	Intital electrical transmission capacities between pairs of regions. The electrical transmission capacity is the capacity disregarding a possible loss (see the table XLOSS). Thus, if there is a loss, a maximum of XCAPINIT MW may be sent into the transmisison line, but at most (XCAPINIT*XLOSS) MW may be extracted.	MW
O Parameter XCOST.inc	XCOST	IRRRE, IRRRI	Electrical transmission cost between pairs of regions. Applies to the electricity entering the transmission line.	EUR2002/MW
O Parameter XLOSS.inc	XLOSS	RRR, RRR	Loss in transmission expressed as a fraction of the power entering the transmission line.	None

File	Source table	Source field
O Parameter BASE_DE_ANC_NEG_VAR_D.inc	Data RRR YYY Primary reserve Demand	Value negative
O Parameter BASE_DE_ANC_POS_VAR_D.inc	Data RRR YYY Primary reserve Demand	Value positive
O Parameter BASE_DE_VAR_T.inc	Data RRR YYY Elec Demand	AnnualElecDemand
	Data RRR TTT Elec Demand	Value
O Parameter BASE_DEMAND_NONSPIN_ANCPOS.inc	Data RRR NNN TTT Secondary reserve	Value
O Parameter BASE_DEMAND_NONSPIN_ANCPOS_N_1.inc	Data RRR YYY Secondary reserve demand	Value positive
O Parameter BASE_DH_VAR_T 1.inc	Data AAA YYY Heat Demand	AnnualHeatDemand
	Data AAA TTT Heat Demand	Value
O Parameter BASE_DH_VAR_T 2.inc	Data AAA YYY Heat Demand	AnnualHeatDemand
	Data AAA TTT Heat Demand	Value
O Parameter BASE_IER3LOWERBOUND_VAR_T.inc	Data AAA TTT IER3 Minimum Heat Capacity Bound	Value
O Parameter BASE_INFLOWHYDRORES_VAR_T.inc	Data RRR TTT Water Inflow Hydrores	Value
	Data RRR YYY Water Inflow	AnnualWaterInflowControllable
O Parameter BASE_RUNRIVER_VAR_T.inc	Data RRR DDD Water Inflow Uncontrollable	Value
	Data Units	MaxPower
O Parameter BASE_RUNRIVER_VAR_T 1.inc	Data RRR WWW Water Inflow Uncontrollable	Value
	Data Units	MaxPower
O Parameter BASE_SOLAR_VAR_T.inc	Data RRR TTT Solar	Value
	Data Units	MaxPower
O Parameter BASE_WIND_VAR Det3.inc	Data RRR TTT NNN Values tree (root node values)	Value
O Parameter BASE_WIND_VAR_NT.inc	Data RRR TTT NNN Values tree	Value
O Parameter BASE_X3FX_VAR_T.inc	Data RRR TTT Elec Exchange Third Countries	Value
O Parameter DEF_STEPS_PRICE.inc	Data RRR Steps Elastic Demand Curve Electricity	DF_PRICE
O Parameter DEF_STEPS_QUANT.inc	Data RRR Steps Elastic Demand Curve Electricity	DF_QUANT
O Parameter DEFP_BASE.inc	Data RRR Region General	Value
O Parameter DHF_STEPS_PRICE.inc	Data AAA Steps Elastic Demand Curve Heat	DF_PRICE
O Parameter DHF_STEPS_QUANT.inc	Data AAA Steps Elastic Demand Curve Heat	DF_QUANT
O Parameter DHFP_BASE.inc	Data AAA Area General	Value
O Parameter DISCOST_E.inc	Data RRR Region General	Value
O Parameter DISCOST_H.inc	Data AAA Area General	Value
O Parameter DISLOSS_E.inc	Data RRR Region General	Value

File	Source table	Source field
O Parameter DISLOSS_H.inc	Data AAA Area General	Value
O Parameter ELEC_SUBSIDY.inc	Data CCC YYY FFF Elec Taxes and Subsidies	ElecTax
O Parameter FDATA.inc	Base Fuels	Fuel
	Base Fuels	SO2
	Base Fuels	CO2
O Parameter FUELPRICE_GJ.inc	Data AAA YYY FFF Fuel Prices	AnnualFuelPrice
O Parameter FUELPRICE_GJ 2.inc	Data AAA YYY FFF Fuel Prices	AnnualFuelPrice
O Parameter GDATA.inc	Data Units	CHP_CB
	Data Units	Ext_CV
	Data Units	Fuel
	Data CCC YYY FFF Fuel Taxes	Value
	Data CCC YYY FFF Fuel Taxes Reduction	Value
	Data Units	MaxEff
	Data Units	LeadTime
	Data Units	LoadLoss
	Data Units	MinPower
	Data Units	MinOperTime
	Data Units	MinDownTime
	Data Units	VarOaMcosts
	Data Units	PartEff
	Data Units	StartUpVarCosts
	Data Units	Type
O Parameter GDATA 1.inc	Data Units	CHP_MaxHeat
	Data Units Calculated using MaxEff, PartEff, MaxPower, MinPower and CHP_CB.	DeSO2
	Data Units Calculated using MaxEff, PartEff, MaxPower, MinPower and CHP_CB.	
O Parameter GKDERATE.inc	Data GGG WWW Unit Group Availability	Availability
O Parameter GKFX_CHARGINGSTORAGE.inc	Data Units	Sto_MaxCharging
O Parameter GKFX_CONTENTSTORAGE.inc	Data Units	Sto_MaxContent
O Parameter GKFXELEC.inc	Data Units	MaxPower
O Parameter GKFXHEAT.inc	Data Units	CHP_MaxHeat
	Data Units	MaxPower

File	Source table	Source field
O Parameter GKMAX_CONTENTHYDRORES.inc	Data RRR WWW HydroReservoir Bounds Data Units	UpperBound Sto_MaxContent
O Parameter GKMIN_CONTENTHYDRORES.inc	Data RRR WWW HydroReservoir Bounds Data Units	LowerBound Sto_MaxContent
O Parameter GSTARTVALUEDATA.inc	Data GGG Start values for simulation Data RRR WWW Reservoir levels	GSSDTIME Value
O Parameter INFOTIME_WEEKDAY.inc	Base Time	BaseTime_Sim
O Parameter M_POL.inc	Data CCC YYY Country specific Annual	Value
O Parameter PROBREACHNODE.inc	Data TTT NNN Probabilities tree	Value
O Parameter PROBREACHNODE Deterministic.inc	Data TTT NNN Probabilities tree (root nodes)	Value
O Parameter TAX_DE.inc	Data CCC Country General	Value
O Parameter TAX_DH.inc	Data CCC Country General	Value
O Parameter TAX_HEATPUMP.inc	Data CCC YYY FFF Elec Taxes and Subsidies	ElecTax
O Parameter XCAPACITY.inc	Data RRR RRR Region-to-Region	Value
O Parameter XCOST.inc	Data RRR RRR Region-to-Region	Value
O Parameter XLOSS.inc	Data RRR RRR Region-to-Region	Value

Appendix F : Output files

OUT file	Out file header	Description	Unit
OUT_BASETIMES.csv	CaseID, BaseTime	Time stamps.	-
OUT_CaseNames.csv	CaseName, CaseID	Case name and Case ID.	-
OUT_ELEC_CONS_T.csv	CaseID, RegionID, BaseTime, Value	Electricity consumption including distribution loss and flexible demand.	MW
OUT_FuelPrice.csv	CaseID, AreaID, FuelName, Value	Fuel price for current simulation year.	EUR2002/MWh
OUT_HEAT_CONS_T.csv	CaseID, AreaID, BaseTime, Value	Realised consumption of heat.	MW
OUT_IGELECCAPACITY_Y.csv	CaseID, UnitGroupID, BaseTime, Value	Available power capacity of generation technologies.	MW
OUT_ISDP_HYDRORES.csv	CaseID, RegionID, BaseTime, Value	Price profile for hydro reservoirs. The water value from the Long-term model.	EUR2002/MWh
OUT_ISDP_ONLINE.csv	CaseID, UnitGroupID, BaseTime, Value	Shadow price for unit being online i.e. the marginal value of increasing the capacity online with 1 MW.	EUR2002/MW
OUT_ISDP_STORAGE.csv	CaseID, UnitGroupID, BaseTime, Value	Shadow price for storage content i.e. the marginal value of increasing the energy stored with 1 MWh.	EUR2002/MWh
OUT_IWIND_AVG_IR.csv	CaseID, RegionID, BaseTime, Value	Average value of wind power production estimated at 12.00 for the coming day. This value is used as the bid from wind power production on the day-ahead market.	MW
OUT_IWIND_REALISED_IR.csv	CaseID, RegionID, BaseTime, Value	Realised wind power production.	MW
OUT_IX3COUNTRY_T_Y.csv	CaseID, RegionID, BaseTime, Value	Fixed exchange with third countries, current simulation year.	MW
OUT_QANCNEGEQ_M.csv	CaseID, RegionID, BaseDate, Value	Price (per day) of reserving capacity for providing negative primary reserve.	EUR2002/day
OUT_QANCPOSEQ_M.csv	CaseID, RegionID, BaseDate, Value	Price (per day) of reserving capacity for providing positve primary reserve.	EUR2002/day
OUT_QEEQDAY_M.csv	CaseID, RegionID, BaseTime, Value	Price on the day-ahead market.	EUR2002/MWh
OUT_QEEQINT_M.csv	CaseID, RegionID, BaseTime, Value	Electricity price on the intraday market.	EUR2002/MWh
OUT_QESTOVOLT_M.csv	CaseID, AreaID, UnitGroupID, BaseTime, Value	Marginal value of increasing the capacity of the electricity storage.	EUR2002/MWh
OUT_QGONLSTART_M.csv	CaseID, AreaID, UnitGroupID, BaseTime, Value	Marginal value of increasing the online capacity.	EUR2002/MW
OUT_QHEQURBAN_M.csv	CaseID, AreaID, BaseTime, Value	Heat price.	EUR2002/MWh
OUT_QHSTOVOLT_M.csv	CaseID, AreaID, UnitGroupID, BaseTime, Value	Marginal value of increasing the capacity of the heat storage.	EUR2002/MWh
OUT_QNONSP_ANCPOSEQ_M.csv	CaseID, RegionID, BaseTime, Value	Price of providing additional secondary reserve.	EUR2002/MWh
OUT_TechnologyData.csv	CaseName, Area, UnitGroup, Parameter, Value	Technology data for each unit group.	Various units
OUT_UNITGROUPSINCASE.csv	UnitGroup, CaseName	Unit groups in the case.	-
OUT_VCONTENTHYDRORES.csv	CaseID, AreaID, BaseTime, Value	Hydro reservoir content.	MWh
OUT_VDEMANDELECFLEXIBLE.csv	CaseID, RegionID, BaseTime, Value	Activated amount of price flexible electricity consumption.	MW
OUT_VGE_ANCNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Capacity reserved for providing negative primary reserve.	MW
OUT_VGE_ANCPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Capacity reserved for providing positive primary reserve.	MW
OUT_VGE_CONSUMED_ANCNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Reservation of loading capacity of heat pumps and electricity storage for providing negative primary reserve by increasing the loading.	MW

OUT file	Out file header	Description	Unit
OUT_VGE_CONSUMED_ANCPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Reservation of loading of heat pumps and electricity storage for providing positive primary reserve by decreasing the loading.	MW
OUT_VGE_CONSUMED_NONSP_ANCNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Loading reserved for providing negative secondary reserve (heat pumps and electricity storages).	MW
OUT_VGE_CONSUMED_NONSP_ANCPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Loading capacity reserved for providing positive secondary reserve (heat pumps and electricity storages).	MW
OUT_VGE_NONSP_ANCNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Production reserved for providing negative secondary reserve.	MW
OUT_VGE_NONSP_ANCPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Production capacity reserved for providing positive secondary reserve.	MW
OUT_VGELEC.csv	CaseID, UnitGroupID, BaseTime, Value	Electricity generation fixed on day-ahead market The variable contains the realised wind power generation for wind power, the run-of-river generation for run-of-river plants and the solar generation for solar cells.	MW
OUT_VGELEC_CONSUMED.csv	CaseID, UnitGroupID, BaseTime, Value	Loading of electricity storage or heat pump fixed on day-ahead market.	MW
OUT_VGELEC_CONSUMED_DNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Decreased loading of electricity storage or heat pump.	MW
OUT_VGELEC_CONSUMED_DPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Increased loading of electricity storage or heat pump.	MW
OUT_VGELEC_CONTENTSTORAGE.csv	CaseID, UnitGroupID, BaseTime, Value	Electricity storage contents.	MWh
OUT_VGELEC_DNEG.csv	CaseID, UnitGroupID, BaseTime, Value	Down regulation of electricity generation.	MW
OUT_VGELEC_DPOS.csv	CaseID, UnitGroupID, BaseTime, Value	Up regulation of electricity generation.	MW
OUT_VGFUELUSAGE.csv	CaseID, UnitGroupID, BaseTime, Value	Fuel consumption.	MW
OUT_VGHEAT.csv	CaseID, UnitGroupID, BaseTime, Value	Heat generation.	MW
OUT_VGHEAT_CONSUMED.csv	CaseID, UnitGroupID, BaseTime, Value	Loading of heat storage.	MW
OUT_VGHEAT_CONTENTSTORAGE.csv	CaseID, UnitGroupID, BaseTime, Value	Heat storage contents.	MWh
OUT_VGONLINE.csv	CaseID, UnitGroupID, BaseTime, Value	Capacity online, equal to available capacity for hydro power and electrical storages.	MW
OUT_VGSTARTUP.csv	CaseID, UnitGroupID, BaseTime, Value	Capacity started up.	MW
OUT_VHYDROSPILLAGE.csv	CaseID, UnitGroupID, BaseTime, Value	Spillage of hydropower due to overflow in reservoirs.	MW
OUT_VOBJ.csv	CaseID, InfoTime, Value	Value of objective function in the JMM. Consists of sum of producer and consumer surplus + infeasibilities penalties in all time periods and nodes weighted with the probablity of each node.	EUR2002
OUT_VOBJ_R_T.csv	CaseID, RegionID, BaseTime, Value	Production and transmission costs : Cost of fuel consumption + Operation and maintainance cost + Start-up costs + Transmission cost + Emission taxes (CO_2, SO_2) + Electricity tariff on electricity used for heating (heat pumps and electrical boilers) - Subsidy on electricity produced using biomass or waste + Tax on fuel usage for producing power and heat in condensing and CHP (applied to Germany) - Tax reduction on fuel usage for producing power and heat in CHP (applied to Germany) + Tax on fuel usage for producing heat in CHP production (applies not to Germany) + Tax on fuels of heatboilers + Change in consumer surplus when price flexible consumption is activated.	EUR2002

OUT file	Out file header	Description	Unit
OUT_VXE_NONSPIN_ANCPOS.csv	CaseID, RegionID1, RegionID2, BaseTime, Value	Reservation of transmission capacity for export of up regulation capacity from RegionID1 to RegionID2.	MW
OUT_VXELEC.csv	CaseID, RegionID1, RegionID2, BaseTime, Value	Electricity export from RegionID1 to RegionID2.	MWh
OUT_VXELEC_DNEG.csv	CaseID, RegionID1, RegionID2, BaseTime, Value	Decreased electricity export from RegionID1 to RegionID2.	MWh
OUT_VXELEC_DPOS.csv	CaseID, RegionID1, RegionID2, BaseTime, Value	Increased electricity export from RegionID1 to RegionID2.	MWh

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