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The Balmorel Model Structure: The Gas add-on Module

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Contents

1 Introduction

This paper describes in detail the model structure of the natural gas add-on module for Balmorel.

The Balmorel model was originally designed for analysis of the power and CHP (combined heat and power) sectors in the Baltic Sea region. The gas add-on module was designed as part of the research project entitled *A Model of - and Analyses of an Integrated Electricity and Natural Gas System*. The project, which was partly financed by the Energy Research Programme under the Danish Energy Authority, involved the following participants: Energinet.dk, Danish Gas Technology Center, Technical University of Denmark, Risø National Laboratory, Ea Energianalyse a/s, Rambøll, Energy Modelling and RAM-løse edb (project management).

This document serves as *stand alone* technical documentation for the natural gas module, however it does not describe the model structure of the Balmorel model core. For documentation on the Balmorel project, getting started with Balmorel, the model structure, theoretical background, data and calibration issues and the main report from the mentioned project see [1], [3], [4], [2], [5] and [7] respectively.

2 Scope of the Gas Module

The gas module add-on features a model of the supply of natural gas from the producer to the consumer. The model is developed with specific emphasis on the Danish natural gas system and market, but the implemented features could in most cases be transferred to describe another market.

The gas module has components, which describe in part the technical aspects of natural gas supply, and in part the commercial and institutional framework facing market agents. Just like the Balmorel model core, the gas module is implemented as a partial equilibrium model with perfect competition. In conjunction with the Balmorel model core, it describes partial equilibrium across markets for electricity, district heating and natural gas, i.e. the three most common forms of network bound energy supply. The model is formulated as a linear programming problem, implemented in the GAMS modelling language (General Algebraic Modeling System[6]).

2.1 Technical Detail

The level of technical detail in the modelling of natural gas supply systems is fairly limited. Constraints on the rate at which quantities can be moved through the system are limited to capacity at border crossings, or interconnectors, and injection, extraction and volumetric capacities of storage facilities.

2.2 Access to Infrastructure

Emphasis is put on the implementation of the entry-exit system of procuring access to transmission networks. Most European Transmission System Operators employ and entry-exit tariffing model, where capacity is procured upon entry into the system and upon exit from the system. Many also feature a commodity charge per cubic meter of gas transmitted. The procurement of access to the transmission network is implemented with a range of capacity products, which conformed to the products that are available from the Danish TSO, Energinet.dk. This form of access is similar to that of most European gas transmission networks, except others may have different durations on the capacity contracts.

Access to storage facilities is implemented by allowing the market to procure capacity in the form of a linear combination of packaged deals for injection, extraction and volumetric capacity. This also supports full independent (i.e. separate booking of capacity for injection...) capacity procurement if the model user makes such contracts available. In addition, a commodity charge for injection is implemented, either by induced electricity costs of injection (making the storage system operator a price respondent electricity consumer), or by some exogenous constant injection commodity charge.

2.3 The Gas Market

In the aforementioned project a data set was generated describing in detail the Danish market for natural gas in the year 2004. In the model, gas demand is divided intro endogenous and exogenous consumption. Exogenous demand is defined in terms of large users, i.e. industrial and commercial users with an annual consumption exceeding 300.000 m^3, and *residual* consumers encompassing users with an annual consumption of less than 300.000 m^3. The endogenous gas consumption is induced by gas-fired generation of electricity and district heating, which originates from the Balmorel model core.

2.4 International Gas Connections

Gas can be sold to - or purchased from - adjacent international markets. This is done either at a fixed price exogenous price, or though a price-quantity profile. The capacity of exports to - and imports from - adjacent systems is constrained, by the capacity of the border station.

3 Connection to the Balmorel model

The gas add-on module is connected to the Balmorel model, through the endogenous gas consumption incurred by the generation of electricity and district heating. This implies that the electricity and/or district heating generator faces an implied gas price, which reflects market's efficient utilization of the gas supply infrastructure and the efficient gas procurement from gas suppliers at production nodes or import markets.

4 Simulation Types

The gas add-on module is compatible with Balmorel's three main model types named BB1, BB2 and BB3. Each model uses a different strategy for simulating a year's worth of operations. Consecutive years are modelled iteratively.

BB1 is a simultaneous optimization of a full year, where investments are not performed endogenously. Time is aggregated so that a number of representative time segments are generated.

BB2 is a simultaneous optimization of a full year, with endogenous investments. Time is aggregated so that a number of representative time segments are generated.

BB3 iteratively optimizes a week at at time with an hourly time resolution.

Naturally some effects, such as seasonal planning of hydro reservoir use, cannot be captured by a simulation of BB3 and therefore certain values are often passed from BB1 and BB2 to BB3.

Limitations and Expected Modifications

Currently the data structure is in a few places bound to the case of the Danish gas markets. This means that certain equations in the GAMS code have references to case specific geographical entities, set elements. These will in due course be generalized and as such are not documented.

5 Model Configuration and Options

The Balmorel model can be configured by using option files. Specific flags can be set to include certain code and data, which change model input and configuration. These flags are created using GAMS *$Setglobal statements.* The principle in the Balmorel options files concept is as follows:

In the model directory we find:

balgams.opt contains GAMS specific options, which can be used to set tolerances, auto-generate output etc. These options are described in [6].

balopt.opt contains options for the Balmorel model core.

5.1 Balmorel core options

Some options following are interdependent. They can be mutually exclusive, or reliant on positive assignment of other options. Far from all combinations have been tested, particularly with respect to add-ons.

Simulation identification

CASEID This is the case identification string. It can be assigned freely however, if the case is a base case to which other cases should be compared the name should be BASECASE. Normally the model in the base directory will be called BASECASE while any variants will have names as appropriate. Model results in the form of GDX files (or ACCESS MDBs) will have the CASEID as filename with the appropriate extension. *Sample assignment: "$Setglobal CASEID BASECASE"*

Model selection

BB1 activates the simultaneous optimization of a full year, where investments are not performed endogenously. Time is aggregated so that a number of representative time segments are generated. *Sample assignment: "$Setglobal BB1 yes"*

BB2 activates the simultaneous optimization of a full year, with endogenous investments. Time is aggregated so that a number of representative time segments are generated. *Sample assignment: "$Setglobal BB2 yes"*

BB3 activates the iterative optimization of weeks at at time with an hourly time resolution, permitting no investments. *Sample assignment: "$Setglobal BB3 yes"*

Data selection

SIMULATEDWEEKS is a shortcut for assigning set elements to the set S. *Sample assignment: "$Setglobal SIMULATEDWEEKS S03,S23,S43,S50"*

The following options selection of time series. Time series for 3 years can be selected by assigning one of the following options to yes. They are mutually exclusive so one and only one should be set positive.

WxH2001 use time series from the year 2001 wrt. electricity and district heating.

WxH2002 use time series from the year 2002 wrt. electricity and district heating.

WxH2003 use time series from the year 2003 wrt. electricity and district heating.

Many data sets exist in several versions and more will be added. The ones which are most often switched between, i.e. for doing sensitivity analysis, have associated options, such as the following:

CO2HIGH when assigned, what is considered to be a "high" level of CO2-prices is applied in the model. *Sample assignment: "$Setglobal CO2HIGH yes"*

Data processing

There are difference ways to process input data into model data. Some have options associated.

timeaggr This option actives an automated time aggregation functionality. It is only used for BB1 and BB2, since BB3 uses the full time resolution. The principal is that the user selects which hours of the year should be combined to form aggregated time segments. The aggregation process is then automated. Finding a good time aggregation can also be automated by the CREATETIME/CREATEDTIME options.

CREATEDTIME This option enables use of an auto-generated time aggregation which is dependent on input data variations. The time aggregation is created using the CREATETIME option.

DECOMP This option enables ad-hoc decommissioning of generation capacity.

Output control

PRINTFILES Enables generation of the traditional text based output files.

MAKEACCESS Create access file from the output. **It is imperative that GAMS is run with "savepoint=2" as a command line parameter.**

Functionality alternatives

In certain areas a minute change in the model can give the model a different, yet usefull interpretation. To avoid limiting future usage according to a singular perspective, options can be used to select between alternatives.

QSTOVOLT1CycleInS Sets the way short term storage cycles are assumed in relation heat and electricity storages.

- yes - There is a single storage cycle for each seasonal element (S)
- otherwise - There are multiple storage cycles for each seasonal element (S)

quickfix When making quick-fix adjustments or tests it is an advantage to use an option to switch it on and off. Also, this can be used as a search word when reviewing quick-fixes.

Add-on inclusion

The development of the Balmorel model has primarily been project driven. At any given time several Balmorel projects are active. The Core/Add-on structure has become the adopted strategy for gathering functionality extensions from individual projects, and avoiding conflicts. A true add-on can be completely removed from the code by simply not setting the associated control option.

COMBTECH Include the combination technologies add-on.

MP Include the market power add-on. (unfinished)

GAS Include the natural gas add-on.

FSS Include the add-on for security of supply.

X3V Include the add-on for price-flexible imports and exports with third countries.

QUAD Use a quadratic demand function (unfinished)

WELFARE Include the welfare add-on.

H2 Include the hydrogen add-on.

NAP Include effects of free allocation of CO2 permits to new market entrants.

Alternative functions

The model structure and data is sometimes used for other functionalities than a Balmorel model simulation. This could be using the data and the data structure to generate input for some other simulation, or perhaps to use GAMS to change data input in the model for future simulations.

CREATETIME This option bypasses the normal execution of a Balmorel simulation. It is used to find suitable aggregation of time for subsequent Balmorel executions by solve a mixed-integer quadratically constrained program. (documentation pending)

Data transference between simulations

MAKEWATER Used in a BB1 or BB2 model to generate water quantities and values to be transferred to BB3.

WATERVAL Used in BB3 to use transferred water values instead of quantities.

MAKEINVEST Used in a BB2 model to generate additional capacity for other models

ADDINVEST Used in a BB1 or BB3 model to load investments as generated in BB2

5.2 Gas add-on module options

The following options pertaining to the gas add-on module.

Functionality alternatives

FREESTORAGE if set, no exogenous capacity charge on gas storage. However capacity tariffs can be interpreted from the marginal of the storage level. value VSTOCK.

FREEGAS This parameter ensures that the fuel cost from Balmorel for natural gas is set to zero for areas which are supplied through the gas module. This option must be set if the

Data processing

SCALEEXP_PRICE activate to enable adjustments to the wellhead price.

PRICESCALE if previous option is set, this factor is multiplied to the price in adjacent systems in all time segments.

GasPriceAdd if SCALEEXP_PRICE is set, this factor is added to the price in adjacent systems in all time segments.

Data selection

MUSTGAS New technology in local district heating areas with existing gas supply must be gas fired, if this option is set.

EXPANDGAS New gas-fired technology is allowed in local district heating areas with no existing gas supply, if this option is set.

ALLOWEH Electricity-to-heat technologies allowed in Denmark if this option is set.

GASSCALE Applies scaling to the objective function. May give performance improvements.

SOLVEMIP Set to yes to use discrete investments in gas infrastructure.

Extensions

These options extend the field of allowed technologies.

micro Option for including micro-chp (unfinished. Don't set)

CAES Option for including compressed air energy storage. (not tested)

These options add detail to the representation of the networks.

MR Geographical resolution at MR level.

HEATING Employ special nodes for larger district heating areas. (unfinished. Don't activate)

PIPELINE Run pipeline simulation. (unfinished. Don't activate)

Data transference between simulation

CAPACITYALLOCATIONS Create an input file for yearly and monthly capacity reservations for use in BB3. Only has effect in BB1 and BB2 simulations.

STORAGEALLOCATIONS Create an input file for gas made available in specific weeks for use in BB3. Only has effect in BB1 and BB2 simulations.

Adjustments for testing

These options should all be off but can be useful in testing. When making quick-fix adjustments or tests it is an advantage to use an option to switch it on and off. Also, this can be used as a search word when reviewing quick-fixes.

NOCAPACITY Turns of capacity reservation functionality.

TRIPLECAPPRICE Triples price of capacity products to exaggerate effects.

6 Sets

Parameters, variables and equations are populated generically in GAMS. This implies that when defining a model component, such as an equation, one can define the component over one or more sets. Hence, an equation e.g. a transmission constraint, would be defined over a set of transmission possibilities, or perhaps a subset of the cartesian square of geographical nodes implying transmission from one node to another. Again the generic formulation is often extended to hold for all time segments and so on.

A number of sets are shared between the gas module and the Balmorel core model structure. The most important ones are listed below:

- Countries: C, CCC
- Regions: IR, RRR
- Areas: IA, AAA
- Years: Y, YYY
- Seasons: S, SSS
- Time period: T, TTT

In general the triple letter sets reflect all possible set elements, whereas the others are specific to the current simulations. As such most input data is defined over the general sets, whereas the actual model is defined over the specific sets.

6.1 Sets Built into the Gas Module

In addition to the above, the gas module uses the following sets.

Item:	Name	Domain
Geography		
Distribution networks	DDD	-
Areas belong to distr. networks	DDDAAA	DDD,AAA
Distr. networks belong to regions	RRRDDD	RRR, DDD
Gas production areas or border crossings	SOURCE	AAA
Areas with possibility for gas storage	STORE	AAA
Contracts		
Gas storage contracts	SCON	-
Components in a gas storage contract	SCONDATASET	-
Time		
Days of the week	DAY	-
Specific hours in specific days	DAYT	DAY, TTT
Months of the year	IMONTH	-
Connection between month, week and day	IWHEN	IMONTH,SSS,DAY
Weeks in months	MONTHSSS	IMONTH,SSS
Investment Options		
Gas infrastructure investments in general	NGINV0	-
Gas infrastructure investments in simulation	NGINV	NGINV0
Types of gas storage facilities	STORETYPE	
Investment of gas storage allowed in areas	STOREINV	STORE, STORETYPE

6.1.1 DDD

The DDD set represents distribution networks. Distribution networks are subordinate of regions, RRR, and superordinate of areas, AAA. The set is mainly used for aggregation of results to distribution level, or for incurring distribution costs.

6.1.2 DDDAAA

This set defines the relationship between distributions networks and areas. The set is a subset of the cartesian product between the DDD and AAA sets. The elements of the product set are included if the area is part of the distribution network.

6.1.3 RRRDDD

This set defines the relationship between regions and distributions networks. The set is a subset of the cartesian product between the RRR and DDD sets. The elements of the product set are included if the distribution network is part of the region.

6.1.4 SOURCE

This subset of areas, AAA, describes areas which feature either gas production or a gas border crossing.

6.1.5 STORE

This subset of areas, AAA, describes areas where a gas storage facility is present or there exists an opportunity to invest in one.

6.1.6 SCON

SCON is the set of available storage contracts. Each element of SCON is associated with a package deal comprised of injection capacity, extraction capacity and volumetric capacity in a virtual storage node.

6.1.7 SCONDATASET

This set contains the static elements of {VOLCAP, EXTCAP, INJCAP, TARIFF}. For each storage contract, SCON, these are used to index the relationship between the procured access rights to capacity and the tariff incurred.

6.1.8 DAY

Days of the week.

6.1.9 DAYT

Which hours of the week in TTT fall in which weekday.

6.1.10 IMONTH

Calender months of the year.

6.1.11 IWHEN

The set associates a month, week and day, by containing the appropriate elements. This set is rather redundant.

6.1.12 MONTHSSS

This set assigns whole weeks, SSS, to be part of a given month, IMONTH. In practice this makes months contain either 4 or 5 complete weeks. The inconsistency in this is resolved by scaling.

6.1.13 NGINV0

This set describes a series of feasible gas infrastructure investment projects. Gas infrastructure investments have compound effects in the model, e.g. the strengthening of a border crossing may effect both import and export capacity, and therefore the projects have associated several parameters to detail the precise impact of a specific project. The set spans the full range of projects the user enters into the model.

6.1.14 NGINV

This subset of NGINV0 contains only those projects, which are included in the current simulation, by user specification.

6.1.15 STORETYPE

There are different types of gas storage facilities with varying investments costs and bundled capacity etc. This set describes the range of storage facility types.

6.1.16 STOREINV

This subset of the cartesian product of storage facility types and storage locations describes, where it is possible to invest in which facility types.

7 Parameters and Scalars

Parameters and scalers in GAMS models are exogenous variables. They can also be used as intermediaries for calculating model input or postprocessing output. Here parameters (and scalars) are described in terms of internal and external parameters. The external parameters are for the user to enter input data. Internal parameters are assigned or calculated on the basis of the external parameters, and they are used in the simulation, either as model coefficients or constants or as bookkeeping parameters between model executions in a simulation. Certain parameters from the Balmorel model core are used in the gas module directly.

The most import of these is:

- Duration of time segment (S,T) in hours, IHOURSINST(S,T)

7.1 External Parameters and Scalars in the Gas Module

The gas module uses the follow external parameters:

Item:	Name	Domain
Demand related		
Variation in residual gas demand	DGRES_VAR	AAA,SSS,TTT
Variation in I& C gas demand	DGOTH_VAR	AAA,SSS,TTT
Tariffs		
Storage contract terms	SCONDATA	SCON,SCONDATASET
Injection tariff	TAU_INJ	-
Annual entry tariff	TAU_EN_Y	-
Annual exit tariff	TAU_EX_Y	-
Monthly entry tariff	TAU_EN_M	IMONTH
Monthly exit tariff	TAU_EX_M	IMONTH
Weekly entry tariff	TAU_EN_W	SSS
Weekly exit tariff	TAU_EX_W	SSS
Daily entry tariff	TAU_EN_D	SSS,DAY
Daily exit tariff	TAU_EX_D	SSS,DAY
Transmission volume tariff	TAU_VOL	-
Distribution tariff	TAU_DIST	DDD
Transferred of capacity procurements		
Yearly transmissions capacity reserved exogenously	TC_EN_Y	YYY
Yearly transmissions capacity reserved exogenously	TC_EX_Y	YYY
Monthly transmissions capacity reserved exogenously	TC_EN_M	YYY,SSS,TTT
Monthly transmissions capacity reserved exogenously	TC_EX_M	YYY,SSS,TTT
Procured gas storage contracts	SC_Y	YYY,SCON
Transferred quantities		
Net-extraction from storage in given week	GSFXW	YYY,STORE,STORETYPE,SSS
Accumulated capacity expansions		
Expansion of volumetric storage	STOREACC	YYY,STORE,STORETYPE
Expansion of injection capacity	INJACC	YYY,STORE,STORETYPE
Expansion of extraction capacity	EXTACC	YYY,STORE,STORETYPE
Expansion of gas export capacity	EXPACC	YYY,SOURCE
Expansion of gas supply capacity	SUPACC	YYY,SOURCE
Adjacent system prices		
Weekly Seasonal Factor for adjacent markets	WSF	SSS
Technical capacities		
Hourly exogenous natural gas supply capacity	SUPPLY_MAX	YYY,SOURCE
Hourly exogenous natural gas export capacity	EXP_MAX	YYY,SOURCE
Injection capacity, exogenous	INJ_MAX	YYY,STORE,STORETYPE
Extraction capacity, exogenous	EXT_MAX	YYY,STORE,STORETYPE
Storage volumetric capacity, exogenous	STORAGE_MAX	YYY,STORE,STORETYPE
Investments		
Investment costs	COST_NGINV	NGINV0
Effect on supply capacity from investment	SUPEFFECT	NGINV0,SOURCE
Effect on export capacity from investment	EXPEFFECT	NGINV0,SOURCE
Storage investment data	GSTOREDATA	STORETYPE,*
Maximum possible capacity at storage location	MAXINVEST	STORE,STORETYPE
Miscellaneous		
Annuity for gas investments	GASANNUITY	-
Storage reserved for emergencies by the TSO	TSOSTORAGE	YYY,STORE,STORETYPE

7.1.1 DGRES_VAR

Variation profile for exogenous residual demand. The profile is supplied on a relative basis. See the IDGRES_Y parameter in section 7.2.1.

7.1.2 DGOTH_VAR

Variation profile for exogenous I& C demand. The profile is supplied on a relative basis. See the IDGOTH_Y parameter in section 7.2.2.

7.1.3 SCONDATA

This parameter contains data for available storage contracts. For each storage contract SCON (see section 6.1.6), is supplied a value for volumetric, injection and extraction capacity available for an also supplied tariff.

7.1.4 TAU_INJ

The parameter contains the commodity charge injecting gas into a storage facility. This is only active if electricity consumption is not linked to injection (see section 5).

7.1.5 TAU_EN_Y

The cost of reserving a unit (MWh/h) of entry capacity for a full year. This influences the objective function in the BB1 and BB2 simulations.

7.1.6 TAU_EX_Y

The cost of reserving a unit (MWh/h) of exit capacity for a full year.The cost of reserving a unit of entry capacity for a full year. This influences the objective function in the BB1 and BB2 simulations.

7.1.7 TAU_EN_M

The cost of reserving a unit (MWh/h) of entry capacity for a given month.The cost of reserving a unit of entry capacity for a full year. This influences the objective function in the BB1 and BB2 simulations.

7.1.8 TAU_EX_M

The cost of reserving a unit (MWh/h) of exit capacity for a given month. This influences the objective function in the BB1 and BB2 simulations.

7.1.9 TAU_EN_W

The cost of reserving a unit (MWh/h) of entry capacity for a given week. This influences the objective function in all simulations.

7.1.10 TAU_EX_W

The cost of reserving a unit (MWh/h) of exit capacity for a given week. This influences the objective function in all simulations.

7.1.11 TAU_EN_D

The cost of reserving a unit (MWh/h) of entry capacity for a given day. This influences the objective function in BB3 simulations only.

7.1.12 TAU_EX_D

The cost of reserving a unit (MWh/h) of exit capacity for a given day. This influences the objective function in BB3 simulations only.

7.1.13 TAU_VOL

Transmission through the transmission network incurs a commodity charge in addition to the capacity charges described above.

7.1.14 TAU_DIST

Tariffs in the distribution networks are commodity based. Normally, the tariff level drops with increasing annual consumption, yet this can not be modelled in linear programming, due to concavity of the cost function. However, as the endogenous part for the natural gas consumption is characterized by large consumers, they generally fall into the same category anyways.

7.1.15 TC_EN_Y

This parameter is used to transfer the reservation of annual entry capacity from BB1 or BB2 to BB3.

7.1.16 TC_EX_Y

This parameter is used to transfer the reservation of annual exit capacity from BB1 or BB2 to BB3.

7.1.17 TC_EN_M

This parameter is used to transfer the reservation of monthly entry capacity from BB1 or BB2 to BB3.

7.1.18 TC_EX_M

This parameter is used to transfer the reservation of monthly exit capacity from BB1 or BB2 to BB3.

7.1.19 SC_Y

This parameter is used to transfer the storage capacity procurements from BB1 or BB2 to BB3.

7.1.20 GSFXW

Net-extraction from storage by weeks and years. This transfer parameter can be generated by BB1 and BB2 simulations. It is used as input in a BB3 simulation.

7.1.21 STOREACC

This parameter contains the yearly accumulated investments in volumetric capacity in gas storage facilities. In a BB2 simulation the parameter is generated and the values can be transferred to a subsequent BB1 or BB3 simulation.

7.1.22 INJACC

This parameter contains the yearly accumulated investments in injection capacity in gas storage facilities. In a BB2 simulation the parameter is generated and the values can be transferred to a subsequent BB1 or BB3 simulation.

7.1.23 EXTACC

This parameter contains the yearly accumulated investments in extraction capacity in gas storage facilities. In a BB2 simulation the parameter is generated and the values can be transferred to a subsequent BB1 or BB3 simulation.

7.1.24 EXPACC

This parameter contains the yearly accumulated effect of investments in export capacity at border crossings. In a BB2 simulation the parameter is generated and the values can be transferred to a subsequent BB1 or BB3 simulation.

7.1.25 SUPACC

This parameter contains the yearly accumulated effect of investments in supply capacity at border crossings or interconnectors. In a BB2 simulation the parameter is generated and the values can be transferred to a subsequent BB1 or BB3 simulation.

7.1.26 WSF

Prices in adjacent markets are dependent on the gas price level in the general Balmorel and adjusted weekly with the *Weekly Seasonality Factor*. This factor can be calculated by the *normalization* of historic gas prices at the relevant adjacent markets.

7.1.27 SUPPLY_MAX

Exogenous hourly supply capacity at a specific source. See the internal ISUPPLY_MAX parameter (section 7.2.7).

7.1.28 EXP_MAX

Exogenous hourly export capacity at a specific border crossing. See the internal IEXP_MAX parameter (section 7.2.8).

7.1.29 INJ_MAX

Exogenous hourly injection capacity at storage facilities. See the internal IINJ_MAX parameter (section 7.1.29).

7.1.30 EXT_MAX

Exogenous hourly extraction capacity at storage facilities. See the internal IEXT_MAX parameter (section 7.2.11).

7.1.31 STORAGE_MAX

Exogenous volumetric capacity at storage facilities. See the internal ISTORAGE_MAX parameter (section 7.2.9).

7.1.32 COST_NGINV

Total investment cost of undertaking a gas infrastructure investment project.

7.1.33 SUPEFFECT

The increase in supply capacity at source nodes resulting from a gas infrastructure investment.

7.1.34 EXPEFFECT

The increase in export capacity at border crossings resulting from a gas infrastructure investment.

7.1.35 GSTOREDATA

Data table describing storage investment options. For each storage type are associated values for investment cost per volume of storage, bundled injection and extraction capacities with a normal storage investment (see section 8.0.34), investment cost for a marginal increase in injection and extraction capacities (see sections 8.0.36 and 8.0.35), electricity consumption for injection and gas consumption for reheating upon extraction.

7.1.36 MAXINVEST

Investments in volumetric storage capacity is limited for instance by geology. This parameter defines the maximal volumetric capacity possible in excess of exogenously defined capacity.

7.1.37 GASANNUITY

Annuity used for investments in gas transmission infrastructure projects. This is implemented separately from the Balmorel core annuity parameter for flexibility.

7.1.38 TSOSTORAGE

For maintaining the pressure balance in a transmission network, or for ensuring emergency supply security a TSO can, with priority, reserve storage volume, reducing the amount of storage available to market agents.

7.2 Internal Parameters and Scalars in the Gas Module

The gas module uses the follow internal parameters:

Item:	Name	Domain
Demand related		
Residual gas demand	IDGRES_Y	AAA,S,T
I& C gas demand	IDGOTH_Y	AAA,S,T
Residual gas demand, weight sum over the variation	IDGRES_SUMVAR	AAA
I& C gas demand, weight sum over the variation	IDGOTH_SUMVAR	AAA
Boundary prices		
Export value of natural gas	IGEX_PRICE	SOURCE,SSS
Wellhead gas price	IGEXT_COST	SOURCE,S
Physical capacities		
Exogenous maximum supply capacity	ISUPPLY_MAX	SOURCE
Exogenous maximum supply capacity	IEXP_MAX	SOURCE
Exogenous maximum storage capacity	ISTORE_MAX	STORE,STORETYPE
Exogenous maximum injection capacity	IINJ_MAX	STORE,STORETYPE
Exogenous maximum extraction capacity	IEXT_MAX	STORE,STORETYPE
Transferred capacity procurements		
Reserved yearly exit capacity	ITC_EX_Y	-
Reserved monthly exit capacity	ITC_EX_M	S,T
Reserved yearly entry capacity	ITC_EN_Y	-
Reserved monthly entry capacity	ITC_EN_M	S,T
Procured access to storage procured	ISC	SCON
Transferred quantities		
Net-extraction from storage by week	IGSFXW	STORE,STORETYPE,SSS

7.2.1 IDGRES_Y

This parameter is the hourly demand rate in absolute terms (MWh/h) for gas in the residual market segment. The value for each time segment is calculated by the following assignment:

$$IDGRES\_Y(IA,S,T) = DGRES(Y,IA)\frac{DGRES\_VAR(IA,S,T)}{IDGRES\_SUMVAR(IA)}$$

This takes place in the annual updating part (see figure 1), which is within the controlling loop over all simulated years Y.

7.2.2 IDGOTH_Y

As above, this parameter is the hourly demand rate in absolute terms (MWh/h) for gas in the I&C market segment. The value for each time segment is calculated by the following assignment:

$$IDGOTH\_Y(IA,S,T) = DGOTH(Y,IA)\frac{DGOTH\_VAR(IA,S,T)}{IDGOTH\_SUMVAR(IA)}$$

This takes place in the annual updating part (see figure 1), which is within the controlling loop over all simulated years Y.

7.2.3 IDGRES_SUMVAR

This internal parameter is the weight sum over the variation in residual gas consumption. See calculation of parameter IDGRES_Y in section 7.2.1.

7.2.4 IDGOTH_SUMVAR

This internal parameter is the weight sum over the variation in I&C gas consumption. See calculation of parameter IDGOTH_Y in section 7.2.2.

7.2.5 IGEX_PRICE

This internal parameter describes the gas price in adjacent markets. The price is calculated from the "fuel price" of natural gas at the border crossing and the weekly seasonality factor (see section 7.1.26).

$$IGEX\_PRICE(SOURCE,S) = (IFUELP\_Y(SOURCE,'NAT\_GAS')*(1+WSF(S))$$

The IFUELP_Y parameter is part of the Balmorel model core and is described in [4]. The 'NAT_GAS' reference is dependent on the presence of a fuel with that name.

7.2.6 IGEXT_COST

This parameter is the wellhead price at a SOURCE node.

7.2.7 ISUPPLY_MAX

Exogenous hourly supply capacity for the current year.

- When running BB1 or BB3 without transference of investments from a BB2 simulation, this parameter represents the total hourly supply capacity from each source.
- When running BB1 or BB3 with transference of investments from a BB2 simulation, this parameter added with SUPACC (section 7.1.25) represents the total hourly capacity.
- When running BB2 this parameter added with supply effect of undertaken investments, SUPEFFECT*VGINFINV (see sections 7.1.33 and 8.0.33), in gas infrastructure represents the total hourly supply capacity.

7.2.8 IEXP_MAX

Exogenous hourly export capacity for the current year.

- When running BB1 or BB3 without transference of investments from a BB2 simulation, this parameter represents the total hourly supply capacity from each source.

- When running BB1 or BB3 with transference of investments from a BB2 simulation, this parameter added with EXPACC (section 7.1.24) represents the total hourly capacity.
- When running BB2 this parameter added with supply effect of undertaken investments, EXPEFFECT*VGINFINV (see sections 7.1.34 and 8.0.33), in gas infrastructure represents the total hourly supply capacity.

7.2.9 ISTORE_MAX

Exogenous volumetric storage capacity of each storage location and type for the current year.

- When running BB1 or BB3 without transference of investments from a BB2 simulation, this parameter represents the total storage capacity.
- When running BB1 or BB3 with transference of investments from a BB2 simulation, this parameter added with STOREACC (section 7.1.21) represents the total capacity.
- When running BB2 this parameter added with any investments in similar type gas storage facility represents the total capacity.

7.2.10 IINJ_MAX

Exogenous injection capacity of each storage location and type for the current year.

- When running BB1 or BB3 without transference of investments from a BB2 simulation, this parameter represents the total injection capacity.
- When running BB1 or BB3 with transference of investments from a BB2 simulation, this parameter added with INJACC (section 7.1.22) represents the total capacity.
- When running BB2 this parameter added with any investments in similar type gas storage facility, GSTOREDATA*VGINVSTORE (see sections 7.1.35 and 8.0.34), and any marginal expansion of injection capacity VGINVINJ (section 8.0.36), represents the total capacity.

7.2.11 IEXT_MAX

Exogenous extraction capacity of each storage location and type for the current year.

- When running BB1 or BB3 without transference of investments from a BB2 simulation, this parameter represents the total extraction capacity.
- When running BB1 or BB3 with transference of investments from a BB2 simulation, this parameter added with EXTACC (section 7.1.23) represents the total capacity.
- When running BB2 this parameter added with any investments in similar type gas storage facility, GSTOREDATA*VGINVSTORE (see sections 7.1.35 and 8.0.34), and any marginal expansion of injection capacity VGINVEXT (section 8.0.35), represents the total capacity.

7.2.12 ITC_EX_Y

This transfer parameter reflects saved yearly exit capacity reservations calculated in a BB1 or BB2 simulation which are imported in a BB3 simulation. The parameter gets values from from TC_EX_Y described in section 7.1.16.

7.2.13 ITC_EX_M

This transfer parameter reflects saved monthly exit capacity reservations calculated in a BB1 or BB2 simulation which are imported in a BB3 simulation. The parameter gets values from from TC_EX_M described in section 7.1.18.

7.2.14 ITC_EN_Y

This transfer parameter reflects saved yearly entry capacity reservations calculated in a BB1 or BB2 simulation which are imported in a BB3 simulation. The parameter gets values from from TC_EN_Y described in section 7.1.15.

7.2.15 ITC_EN_M

This transfer parameter reflects saved monthly entry capacity reservations calculated in a BB1 or BB2 simulation which are imported in a BB3 simulation. The parameter gets values from from TC_EN_M described in section 7.1.17.

7.2.16 ISC

This internal parameter contains the storage capacity contracts procured in the current year. The parameter gets values from from SC_Y described in section 7.1.19.

7.2.17 IGSFXW

This parameter is the net-extraction from storage during specific weeks of a specific year. It is only used in BB3 and can be generated by BB1 or BB2. The transfer parameter associated with this internal parameter is GSFXW described in section 7.1.20.

8 Variables

Item:	Name	Domain
Physical quantities		
The outtake at location (MWh/h)	VGUD	AAA,S,T
Gas storage level (MWh)	VSTOCK	STORE,STORETYPE,S,T
Gas injection rate into storage facility (MWh/h)	VINJ	STORE,STORETYPE,S,T
Gas extraction rate from storage facility (MWh/h)	VEXT	STORE,STORETYPE,S,T
Gas export rate (MWh/h)	VEXP	SOURCE,S,T
The inflow rate at node (MWh/h)	VSUP	SOURCE,S,T
Capacity procurement		
Reserved ENTRY Transmission Capacity, yearly	VTC_EN_Y	-
Reserved ENTRY Transmission Capacity, monthly	VTC_EN_M	IMONTH
Reserved ENTRY Transmission Capacity, weekly	VTC_EN_W	S
Reserved ENTRY Transmission Capacity, daily	VTC_EN_D	S,DAY
Reserved EXIT Transmission Capacity, yearly	VTC_EX_Y	-
Reserved EXIT Transmission Capacity, monthly	VTC_EX_M	IMONTH
Reserved EXIT Transmission Capacity, weekly	VTC_EX_W	S
Reserved EXIT Transmission Capacity, daily	VTC_EX_D	S,DAY
Storage capacity procured	VSC	SCON
Investments		
Investments in gas transmission infrastructure	VGINFINV	NGINV
Investment in gas storage capacity	VGINVSTORE	STORE,STORETYPE
Marginal expansion of gas extraction capacity	VGINVEXT	STORE,STORETYPE
Marginal expansion of gas injection capacity	VGINVINJ	STORE,STORETYPE

8.0.18 VGUD

This variable contains the outtake at a specific consumption node. It connects the national gas balance QGEQ (section 9.0.37) and the local balance QCONSUMPTION (section 9.0.38).

8.0.19 VSTOCK

Quantity in storage facility at the beginning of the current time period (MWh).

8.0.20 VINJ

Injection rate into storage facility (MWh/h).

8.0.21 VEXT

Extraction rate from storage facility (MWh/h).

8.0.22 VEXP

Export rate to adjacent market (MWh/h).

8.0.23 VSUP

Import or production rate at production node or border crossing (MWh/h).

8.0.24 VTC_EN_Y

Number of annual entry capacity products procured by the market as a whole (MWh/h/year). This variable is only active in the BB1 or BB2 models. In BB3 this is given by the parameter ITC_EN_Y (section 7.2.14)

8.0.25 VTC_EN_M

Number of monthly entry capacity products procured by the market as a whole (MWh/h/month). This variable is only active in the BB1 or BB2 models. In BB3 this is given by the parameter ITC_EN_M (section 7.2.15)

8.0.26 VTC_EN_W

Number of weekly entry capacity products procured by the market as a whole (MWh/h/week).

8.0.27 VTC_EN_D

Number of daily entry capacity products procured by the market as a whole (MWh/h/day). This variable is only active in the BB3 model.

8.0.28 VTC_EX_Y

Number of annual exit capacity products procured by the market as a whole (MWh/h/year). This variable is only active in the BB1 or BB2 models. In BB3 this is given by the parameter ITC_EX_Y (section 7.2.12)

8.0.29 VTC_EX_M

Number of monthly exit capacity products procured by the market as a whole (MWh/h/month). This variable is only active in the BB1 or BB2 models. In BB3 this is given by the parameter ITC_EX_M (section 7.2.13)

8.0.30 VTC_EX_W

Number of weekly exit capacity products procured by the market as a whole (MWh/h/week).

8.0.31 VTC_EX_D

Number of daily exit capacity products procured by the market as a whole (MWh/h/day). This variable is only active in the BB3 model.

8.0.32 VSC

This variable describes the number of storage capacity products procured by the market as a whole.

8.0.33 VGINFINV

This binary variable indicates if a gas infrastructure investment project has been undertaken or not. The as soon as the variable is set during a model simulation it is fixed to 1 in the following years. If the model is simulated as a linear programming relaxation, the variable's lower bound is set to the level of the previous yearly iteration.

8.0.34 VGINVSTORE

This variable represents an investment in gas storage facilities. The investment is limited by the MAXINVEST parameter (section 7.1.36). The investment provides a combination of volumetric, injection and extraction capacity as defined in GSTOREDATA (section 7.1.35).

8.0.35 VGINVEXT

This investment variable represents a marginal expansion of the extraction capacity of a storage facility. The associated investment cost is defined in GSTOREDATA (section 7.1.35).

8.0.36 VGINVINJ

This investment variable represents a marginal expansion of injection capacity of a storage facility. The associated investment cost is defined in GSTOREDATA (section 7.1.35).

9 Equations

The current version of the add-on lacks generality in some areas. First and foremost, many variables and equations are defined implicitly with respect to 'Denmark'. This is for example the case for export and supply variables, where for instance export implies export from Denmark without a generic representation, with respect to the country of origin. The result of this lack of generality can be seen in equations such as QGEQ and QGSVERIGE (sections 9.0.37 and 9.0.41 respectively). Here the export quantity is an outgoing flow in the first equation and an incoming flow i the other. A revision of this will take place eventually, but as it is very encompassing no immediate time-frame has been set.

Item:	Name	Domain
Physical balances		
Gas balance at Gas Pool	QGEQ	S,T
Gas balance at consumption node	QCONSUMPTION	AAA,S,T
Gas storage balance	QGSTOREBAL	STORE,STORETYPE,S,T
Net gas storage for week	QGSFXW	STORE,STORETYPE,S
Gas balance in Sweden	QGSVERIGE	S,T
Contractual obligations		
Entry capacity reservation constraint	QTransEntryCap	S,T
Exit capacity reservation constraint	QTransExitCap	S,T
Volumetric storage capacity reservation constraint	QStoreVol	S,T
Injection capacity reservation constraint	QStoreInj	S,T
Extraction capacity reservation constraint	QStoreExt	S,T
Capacity Constraints		
Supply limit at supply node	QGSUPPLY_MAX	SOURCE,S,T
Export limit at supply node	QGEXP_MAX	SOURCE,S,T
Injection limit at storage node	QGINJ_MAX	STORE,STORETYPE,S,T
Extraction limit at storage node	QGEXT_MAX	STORE,STORETYPE,S,T
Storage limit at storage node	QGSTORE_MAX	STORE,STORETYPE,S,T

9.0.37 QGEQ

This equation is a national gas balance for each time segment of:

- Gas supply, section 8.0.23
- Gas export, section 8.0.22
- Gas storage extraction - less gas consumption for reheating, section 8.0.21

- Gas storage injection, section 8.0.20
- Local gas consumption, section 8.0.18

The associated dual value of the equation divided by the length of the time segment (IHOURSINST) is resemblant of a national gas price, or a "wholesale price".

9.0.38 QCONSUMPTION

This equation ensures at a local level that sufficient quantities are extracted from the national market to supply the local market, thus balancing:

- Local gas consumption (total), section 8.0.18
- Residual gas consumption, section 7.2.1
- I& C gas consumption, section 7.2.2
- Gas consumption for electricity and district heating.

The associated dual value of the equation divided by the length of the time segment (IHOURSINST) is resemblant of a local gas price, or a "retail price".

9.0.39 QGSTOREBAL

Equation ensures balance in the storage facilities by balancing:

- Gas in storage at beginning of time segment, section 8.0.19
- Gas storage extraction, section 8.0.21
- Gas storage injection, section 8.0.20
- Gas in storage at beginning of next time segment, section 8.0.19

This storage balance is only applied in BB1 or BB2. In BB3 equation QGSFXW (section 9.0.40) is used instead.

The associated dual value of the equation implies a marginal value of an extra MWh of gas at the beginning of the time segment, or the price a marketer would require for his gas in storage.

9.0.40 QGSFXW

Equation ensures balance in the storage facilities by balancing:

- Net-extraction from storage in current week, section 7.2.17
- Gas storage extraction, section 8.0.21
- Gas storage injection, section 8.0.20

This storage balance is only applied in BB3. In BB1 and BB2 equation QGSTOREBAL (section 9.0.39) is used instead.

The associated dual value of the equation implies a marginal value of an extra MWh of gas during the current week, or the price a marketer would require for his gas in storage.

9.0.41 QGSVERIGE

This equation (which upon revision will we replaced by QGEQ and QCONSUMPTION, sections 9.0.37 and 9.0.38) ensures a gas quantity balance in the Swedish gas market by balancing:

- Gas exported from Denmark to Sweden. section 8.0.22
- Residual gas consumption, section 7.2.1
- I&C gas consumption, section 7.2.2
- Gas consumption for electricity and district heating
- Gas storage extraction - less consumption for reheating, section 8.0.21
- Gas storage injection, section 8.0.20

The associated dual value of the equation divided by the length of the time segment is resemblant of a Swedish gas price.

9.0.42 QTransEntryCap

This equation ensures that sufficient entry capacity is reserved in the transmission system.

The level of entry defined by

- The sum of supply (production and imports), section 8.0.23

Must in all time segments be less than

- Yearly entry capacity reserved, sections 8.0.24 (BB1-2), 7.2.14(BB3)
- Monthly entry capacity reserved, sections 8.0.25 (BB1-2), 7.2.15 (BB3)
- Weekly entry capacity reserved, section 8.0.26
- Daily entry capacity reserved, section 8.0.27 (BB3 only)
- Supply capacity effect of investments undertaken in current year, sections 8.0.33, 7.1.33

The supply capacity effect of investments is included in this equation in recognition that the tariffs represent amortization of previous investments. Thus market players should not be faced by both the investment cost and the tariff.

The associated dual value of the equation divided by the length of the time segment (IHOURSINST) is resemblant of a perfect trading price for an hours worth of entry capacity.

9.0.43 QTransExitCap

This equation ensures that sufficient exit capacity is reserved in the transmission system.

The level of exit defined by

- Sum of local consumption, section 8.0.18
- Sum of export to other countries, section 8.0.22

Must in all time segments be less than

- Yearly exit capacity reserved, sections 8.0.28 (BB1-2), 7.2.12(BB3)
- Monthly exit capacity reserved, sections 8.0.29 (BB1-2), 7.2.13 (BB3)

- Weekly exit capacity reserved, section 8.0.30
- Daily exit capacity reserved, section 8.0.31 (BB3 only)
- Export capacity effect of investments undertaken in current year, sections 8.0.33, 7.1.34

The export capacity effect of investments is included in this equation in recognition that the tariffs represent amortization of previous investments. Thus market players should not be faced by both the investment cost and the tariff.

The associated dual value of the equation divided by the length of the time segment (IHOURSINST) is resemblant of a perfect trading price for an hour's worth of exit capacity.

9.0.44 QStoreVol

This equation ensures that sufficient volumetric capacity rights are procured. The level of storage (section 8.0.19) must always be less than or equal to:

- The sum of storage products procured, sections 8.0.32, 7.1.3.
- less the investments in storage capacity (BB2 only), section 8.0.34

The investments in storage capacity are included in this equation in recognition that the tariffs represent amortization of previous investments. Thus market players should not be faced by both the investment cost and the tariff.

The associated dual value of the equation is resemblant of a perfect trading price for a unit of storage volumetric capacity.

9.0.45 QStoreInj

This equation ensures that sufficient injection capacity rights are procured. The rate of injection (section 8.0.20) must always be less than or equal to:

- The sum of storage products procured, sections 8.0.32, 7.1.3.
- less the injection effect investments in storage capacity (BB2 only), section 8.0.34, 7.1.35
- less the marginal expansion of injection capacity (BB2 only, section 8.0.36

The investments in injection capacity are included in this equation in recognition that the tariffs represent amortization of previous investments. Thus market players should not be faced by both the investment cost and the tariff.

9.0.46 QStoreExt

This equation ensures that sufficient extraction capacity rights are procured. The rate of extraction (section 8.0.21) must always be less than or equal to:

- The sum of storage products procured, sections 8.0.32, 7.1.3.
- less the extraction effect investments in storage capacity (BB2 only), section 8.0.34, 7.1.35
- less the marginal expansion of extraction capacity (BB2 only, section 8.0.35

The investments in extraction capacity are included in this equation in recognition that the tariffs represent amortization of previous investments. Thus market players should not be faced by both the investment cost and the tariff.

9.0.47 QGSUPPLY_MAX

Technical constraint on production or import. The level of incoming gas supply (section 8.0.23) must be less than

- Existing capacity, section 7.2.7
- Supply capacity effect of investments, sections 7.1.33, 8.0.33

A dual variable to this equation which is not zero indicates that a congestion charge is added cost of supply. This can be interpreted in different ways.

- When the supply variable is production, the exogenous wellhead price (section 7.2.6) is too low. The realization of the wellhead price is thus this congestion charge, plus the exogenous component. This holds as long as there is no or limited upstream competition. If there is upstream competition this implies rent for the offshore pipeline operator.
- When the supply variable is imports from adjacent markets, the exogenous price in adjacent markets could be too low in comparison to the onshore wholesale market price. As such, if there is competition in the adjacent market, the pipeline transmission system operators in both countries would raise transport prices to match the congestion charge. If there is not competition in the adjacent market, then the adjacent market price is raised by the seller to match the congestion charge.

This equation is an primitive bound in BB1 and BB3.

9.0.48 QGEXP_MAX

Technical constraint on export. The level of outgoing gas (section 8.0.22) must be less than

- Existing capacity, section 7.2.8
- Export capacity effect of investments, sections 7.1.34, 8.0.33

A dual variable to this equation which is not zero indicates that a congestion charge is subtracted from the value of exports. This charge either falls to the agent in the adjacent market or is shared by the transmission system operators on both sides of the border.

This equation is an primitive bound in BB1 and BB3.

9.0.49 QGINJ_MAX

Technical constraint on injection into storage. The rate of gas injection (section 8.0.20) must be less than

- Existing capacity, section 7.2.10,
- injection effect investments in storage capacity, section 8.0.34, 7.1.35
- and the marginal expansion of injection capacity, section 8.0.36

A dual value to this equation which is not zero indicates that a congestion charge is levied upon injection. This indicates that the capacity products, with respect to injection are underpriced.

This equation is an primitive bound in BB1 and BB3.

Figure 1: General simulation flowchart.

9.0.50 QGEXT_MAX

Technical constraint on extraction from storage. The rate of gas extraction (section 8.0.21) must be less than

- Existing capacity, section 7.2.11,
- injection effect investments in storage capacity, section 8.0.34, 7.1.35
- and the marginal expansion of injection capacity, section 8.0.35

A dual value to this equation which is not zero indicates that a congestion charge is levied upon injection. This indicates that the capacity products, with respect to extraction are underpriced.

This equation is an primitive bound in BB1 and BB3.

9.0.51 QGSTORE_MAX

Technical constraint on volumetric gas storage capacity. The quantity in storage (section 8.0.19) must be less than

- Existing capacity, section 7.2.9,
- and investments in storage capacity, section 8.0.34

A dual value to this equation which is not zero indicates that a congestion charge is levied upon storage capacity. This indicates that the capacity products, with respect to stored quantity are underpriced.

This equation is an primitive bound in BB1 and BB3.

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