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# Project memo

## User manual for multimarket functionality prototype in ProdRisk

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### Summary

This document is a user manual for running the new (by spring 2017) prototype version of ProdRisk for simulation and optimization of supply in several market types, e.g. day-ahead, intraday, and reserves (both procurement and activation, up and down, several reserve qualities).

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## 1 Introduction

This is a user manual for how to run a new prototype of ProdRisk for simulation of supply in multiple power markets. The document explains how to set up the additional input-files for the multi-market simulation, and it explains the content of new output-files from this simulation. See the user manuals for ProdRisk and EMPS for further information of how to run ProdRisk.

ProdRisk is owned by SINTEF Energy Research and is used by several hydropower producers in the Nordic area. The prototype version was developed within the HydroBalance project (2013 – 2017) to be able to account for a hydropower producer's income in several market types in addition to the traditional day-ahead market. The following markets are included in the new version:

- Day-ahead, such as Nord Pool Spot.
- Intraday, such as Elbas. Several timeframes can be included.
- Reserve power, such as RKOM in Norway. Several reserve qualities (e.g. FCR, FRR and RR), and both positive and negative reserves.
- Activation of reserves, such as the RK market in Norway. Only for one reserve quality (RR).

The developed methodology calculate the supply in day-ahead and subsequent markets (intraday and activation of reserves) in a sequential optimization procedure. The day-head market is treated as the main market, and the supply for this market in a given hour is calculated as if it was the only market. Thereafter, the producer adjust the total position for any given hour when new prices are revealed in subsequent markets. The supply of reserve power (in MW), which reduces the available capacity for the day-ahead and intraday markets, is optimized iteratively on the outside of the sequential optimization procedure. See [1] and [2] for additional information about the algorithm.

The new prototype is based on version 9.6 of ProdRisk, and it is committed in the SVN system with the following name: ProdRisk\_MultiMarket (svn/prodpb/branches/ProdRisk\_MultiMarket).

The extra input needed to run the multi-market version of ProdRisk are:

- MultiMarket.xml
- Reserve power prices
- Price series for day-ahead, intraday and for activation of reserves (up and down). The price series are specified as usual for ProdRisk,

The new output files are:

- Incomemultimarket.csv
- Reservedpower.csv
- Production.csv
- Reservoir.csv

The content in new input- and output-files are described in this document.

There is no environmental variable or password for the new functionality. ProdRisk will go into the multi-market mode if the file MultiMarket.xml exists.

## 2 MultiMarket.xml

### 2.1 Overview of structure in file

In the following we describe the controlling input-file for the multi-market version of ProdRisk. See Section 0 for an example of how the file can be set up. The MultiMarket.xml file is an xml-file and contains the following xml-groups:

```
<?xml version="1.0"?>
<MultiMarket>                                     ... </MultiMarket>
<CapacityMarket>
  <GenerellCapMarket>                             ... </GenerellCapMarket>
  <CapacitySystem>                               ... </CapacitySystem>
  <CapacityModule ModulNr="" ModulName="">      ... </CapacityModule>
</CapacityMarket>
```

Here, <MultiMarket> is the first headline or group in the xml file. The corresponding section start by the text <MultiMarket> and it end by the text </MultiMarket>. This text is not shown, but it is indicated by the "...". Similarly, <GenerellCapMarket> and <CapacitySystem> are headlines/groups below the headline/superstructure <CapacityMarket>. In <CapacityModule ModulNr="" ModulName=""> there is also to attributes: ModulNr and ModulName. ModulNr are required and ModulName is an optional, more about the attribute in 2.3.4.

Within each group, a set of variables can be specified with a name, value, and a comment. Each variable is specified by the elements: NAME, VALUE and COMMENT. The xml syntax for specifying one variable with those elements is:

```
<Variable> <NAME> ... </NAME> <VALUE>...</VALUE> <COMMENT> ...</COMMENT>
</Variable>
```

Here, the description of a variable start with <Variable> and ends with </Variable>. The name of the variable is to be specified between <NAME> and </NAME>, i.e. at the first ... occurrence. The value of the variable is to be specified between <VALUE> and </VALUE>, i.e. at the second ... occurrence. Finally, a comment can be provided between <COMMENT> and </COMMENT>.

The elements NAME and VALUE are required, whereas the element COMMENT is optional and only intended for making the file more understandable.

In the following we will explain the content of specific variables specified within each of the mentioned groups above. The structure of this explanation follows the structure of the file.

## 2.2 <MultiMarket>

The MultiMarket group is an overall controller of the multi market concept in the new prototype. This group control the set-up of which markets that exist in the simulation, as well as the printed results. The variables that are specified in this group is shown in Table 1 and explained further in the following.

**Table 1 Parameters in the MultiMarket group. Default values (applied if no value is specified) are shown for an example where 3 price scenarios/market have been specified in ProdRisk.**

<NAME>	<VALUE>	<COMMENT>
LUseMultiMarket	F	Value specifies if MultiMarket should be used. True (T) for yes, and false (F) for no.
EnergyMarketName	Market 1, Market 2, Market 3	Energy market name.
PriorityOfMarket	1,2,3	Sequence in calculation of supply to markets. Here "1" refers to first market mentioned in MarketName.
RefMarketStrategy	3	Reference market in strategy calculation. Default is last element specified for PriorityOfMarket.
RefMarketReservoir	3	Reference market for reservoir operation. Default is same value as in RefMarketStrategy.
LWriteReservoir	F	Write reference reservoir for all time step
LWriteProduction	F	Write production in different market

### Detailed explanation of variable names in Table 1

**LUseMultiMarket** is a logical for turning on (true, T) and of (false, F) the new option. If this line is not specified or false, multimarket will not be used. Default is F (false).

**EnergyMarketName** is a string with name on the different energy markets. By energy market we here mean electricity markets where the supplied quantity is measured in MWh. Only those markets should be mentioned here, as apposed to markets where the quantity is measured in MW. The energy markets has a corresponding price scenario, which is described later (3.1). The number of market names mentioned for this variable should be identical to the number of price scenarios specified in ProdRisk. If no names are provided, the default names "Market X", where X is from one to number of price scenarios, will be created. **NB: The market must be called "RK", "TR" or "RR"** if the reserved power/capacity specified for the whole system shall be available. Reserves types specified specifically for individual units will never be available for the energy markets.

**PriorityOfMarket** is a list of integers and control how to calculate the results. The supply for the first mentioned market is calculated first, and so on. The number of PriorityOfMarket must be equal to number of price scenarios or MarketName must not be defined. Default one, two, three etc, depending on the number of price scenarios defined.

**RefMarketStrategy** is an integer that controls which market that should be used to calculate cuts (water values). This is carried out in the strategy/backward part of ProdRisk. The value should be between one and the number of price scenarios/market specified. The default market is the last market, i.e. the number of price scenarios specified.

**RefMarketReservoir** is an integer and controls which market should be used as reference market for reservoir operation. This should always be the last cleared marked. Default is value of RefMarketStrategy.

**LWriteProduction** is a logical variable and controls if production in the different market should be written to an output file or not. Values are T, for true/yes, and F, for false/no. Default is F.

**LWriteReservoir** is a logical and controls if reservoir operation should be printed for all load periods. Values are T, for true/yes, and F, for false/no. Default is F.

## 2.3 <CapacityMarket>

### 2.3.1 Specification of reserve capacity supply

The headline CapacityMarket (cf. Section 2.1) group is a headline, or superstructure of groups, associated to power reservation. This is information regarding the supply of products where the quantity is measured in MW<sup>1</sup>. Within <CapacityMarket>, there are three groups defined: GenerellCapMarket, CapacitySystem and CapacityModule. The content in each of them will be described in the following subchapter. General information about reserve markets is mostly specified in the group GenerellCapMarket, whereas the group CapacitySystem contain the specifications for capacity reservation in the system (i.e. the whole simulated watercourse), and CapacityModule contain all specifications related to specific units in the system.

### 2.3.2 <GenerellCapMarket>

This group is an overall controller of power reservation. The variables that are specified in this group is shown in Table 2 and explained further in the following.

---

<sup>1</sup> The corresponding capacity (reserved power) is held back from day-ahead and intraday markets, and thus it is available for balancing in real time. However, so far we have not implemented any explicit requirement that capacity should be spinning or that there should be water behind the turbines.

**Table 2 Parameters in the GenerellCapMarket group. Default values (applied if no value is specified) are shown.**

<NAME>	<VALUE>	<COMMENT>
NamePowerPrice		Name on file with power reservation prices
DimWeek	52	Week horizon in CapacityModule

Detailed explanation of variable names in Table 2

**NamePowerPrice** identifies the name on the file with power reservation prices. The file shall contain all prices where the quantity is measured in MW. Thus prices for different reserve qualities/types, and for both up and down regulation shall be included. The structure of that file will be explained later. If no file name is provided, all reserve prices are set to zero.

**DimWeek** is an integer for week horizon in CapacityModule. Minimum value is 52. If simulated weeks is larger than DimWeek last input year will repeat itself. Default is 52 weeks.

### 2.3.3 <CapacitySystem>

This group is a controller of capacity reservation for the whole analyzed production system. This group control the iteration/optimization concept for capacity reservation. The corresponding reserves will only be available in energy markets called "RK", "TR" or "RR", which are abbreviations for the following synonymous (more or less): regulerkraft, tertiary reserves, and replacement reserves.

One have to specify the attributes ModNr and ModulName *only if* some of the capacity in the production system cannot be utilized for providing reserves, e.g. because the production is not regulated or it cannot be controlled on short notice. However, if at least one unit must be excluded from the provision of power reserves, then one *have to specify all modules* in the ProdRisk dataset that actually can provide reserves.

For the set of units that can provide reserves, the corresponding constraint in ProdRisk will be for the sum of the units, i.e. ProdRisk will for each hour and scenario optimize which capacity that is held back (upward regulation reserves) and which capacity that must produce (downward regulation reserves). Those constraints may or may not be binding in the optimization in any given hour and scenario.

The variables that are specified in this group are shown in Table 3 and explained further in the following.

**Table 3 Parameters in the CapacitySystem group. Default values (applied if no value is specified) are shown.**

<NAME>	<VALUE>	<COMMENT>
NStep	1	Number of steps in ReservedUp and ReservedDown
ItStepUp	0	% of total capacity reserved for up regulation
ItStepDown	0	% of total capacity reserved for down regulation
LControlAll	T	Control all steps in ReservedUp and ReservedDown
Activation	100	% of reserved capacity that will be activated in RK,RR
ModNr	0	Unit number can participate in reserved power system
Column	1	Column in NamePowerPrice where up prices is located

Detailed explanation of variable names in Table 3

**NStep** is number of possible combinations for supply of reserve power to be evaluated in the optimization.<sup>2</sup> The combination identifies the power reservation for up- and down-regulation power as a share (percent) of the total capacity. The corresponding values are defined and separately in the variables ItStepUp and ItStepDown. The sum of the two numbers in those variables cannot be higher than 100% for any combination.

**ItStepUp** is a list that specifies how much of the capacity should be reserved for upward regulation in the different combinations to be evaluated by the algorithm. A given value, e.g. the first value, will be tested for each week in the planning period. The value is constant within any given week. The number of values in this list must be equal to NStep. Values are between zero and hundred, and the unit is [%]. The default value is zero.

**ItStepDown** is a list that specifies how much of the capacity should be reserved for downward regulation in the different combinations to be evaluated by the algorithm. A given value, e.g. the first value, will be tested for each week in the planning period. The value is constant within any given week. The number of values in this list must be equal to NStep. Values are between zero and hundred, and the unit is [%]. The default value is zero.

**LControlAll** controls if all combinations (i.e. NStep different combinations) are to be evaluated, or if the algorithm shall stop looking for a better solution whenever the evaluated objective decreases in the consecutive evaluation of combinations specified. Notice: If both up- and down-regulation is specified, it is typically necessary to seek through all combinations to find the best value. If the value is T (i.e. true), all combinations will be tested. If the value is F (i.e. false), the algorithm will stop when the evaluated objective goes down from one evaluation to the next. The default value is T.

**Activation** is an float number and tells in [%] how much of the reserved capacity can be activated in energy market RK,TR,RR. Default is all capacity can be activated, 100 %.

**ModNr** is an integer and include a unit number, i.e. a module number in the ProdRisk dataset. When specified, this unit can contribute to the supply of power reserves. If no modules are

<sup>2</sup> The algorithm will test all combinations, and choose the best combination for each week in the planning period. The same value is applied for all stochastic scenarios and for all hours within a week.

specified, then all modules can participate. This tag must repeat itself if several modules should be included.

**Column** is an integer and tells the program where (i.e. column number) to look for the power reserve prices for upward regulation in the specified file (the file name is specified in the variable NamePowerPrice in Table 2). Downward regulation prices shall be located in the column next to the upward regulation prices. The default value for the Column variable is one.

### 2.3.4 <CapacityModule>

This group is a controller of capacity reservation for specific units. This reservation comes in addition to any reservation in <CapacitySystem>, and the corresponding capacity will not be available in any MWh market. This can e.g. be used for specifying FCR (primary) and/or FRR (secondary) reserve types, and assigning corresponding reserves to the capacity in dedicated modules. The advantage of this capacity reservation specification is therefore that income from several reserve qualities can be accounted for.

One have to specify a module number in the attribute ModulNr and if desirable include a module name in ModulName (this is optional).

There is not an optimization for capacity reservation on module level. There is no guarantee that there will be a feasible solution when specifying constraints on the utilization of capacity in modules, e.g. regarding minimum production, up- and downregulation, minimum flows and water behind the turbine.

The CapacityModule group is repeated for each module providing reserves. If same module number by a mistake is mentioned more than once, first read values will be used.

The variables that are specified in this group are shown in Table 4 and explained further in the following.

**Table 4 Parameters in the CapacityModule group. Default values (applied if no value is specified) are shown.**

<NAME>	<VALUE>	<COMMENT>
LastWeekCap	52,0,0	Last week with reserved capacity for up and down
MinProduction	0	Minimum production on unit
Column	1	Column in NamePowerPrice where up prices is located

Detailed explanation of variable names in Table 4

**LastWeekCap** is a matrix with three values, which is a combination of integer and float. First value tells the last week the specified capacity is valid. Second and third value are reserved capacity in [MW] for up- and downregulation respectively. It is only possible to give reservation on a weekly level. If DimWeek is 52 and last specified week is 40, all weeks after 40 until 52 have zero capacity reservation. To include various capacities for different weeks repeat this group with a new week number and a new capacity. Default values is zero capacity.

**MinProduction** is a float variable and specifies minimum production in [MW] for use of capacity reservation. This variable tells if unit must be spinning ( $>0$ ) or not ( $=0$ ). Default is zero.

**Column** is an integer and tells the program where (i.e. column number) to look for the power reserve prices for upward regulation in the specified file (the file name is specified in the variable NamePowerPrice in Table 2). Downward regulation prices shall be located in the column next to the upward regulation prices. The default value for the Column variable is one. As a column number is specified per module, the type of reserves provided by the module is specified indirectly by the price-series existing in the column number.

## 2.4 Example of content in MultiMarket.xml

```

<?xml version="1.1"?>
<MULTIMARKET>
  <Variable> <NAME> LUseMultiMarket </NAME> <VALUE> T </VALUE> </Variable>
  <Variable> <NAME> EnergyMarketName </NAME> <VALUE> DA,RK </VALUE> </Variable>
  <Variable> <NAME> RefMarketStrategy </NAME> <VALUE> 2 </VALUE> </Variable>
  <Variable> <NAME> RefMarketReservoir </NAME> <VALUE> 2 </VALUE> </Variable>
  <Variable> <NAME> PriorityOfMarket </NAME> <VALUE> 1,2 </VALUE> </Variable>
  <Variable> <NAME> LWriteReservoir </NAME> <VALUE> T </VALUE> </Variable>
  <Variable> <NAME> LWriteProduction </NAME> <VALUE> T </VALUE> </Variable>
</MULTIMARKET>
<CapacityMarket>
  <GenerellCapMarket>
    <Variable> <NAME> NamePowerPrice </NAME> <VALUE> PowerPrice.csv </VALUE> </Variable>
    <Variable> <NAME> DimWeek </NAME> <VALUE> 52 </VALUE> </Variable>
  </GenerellCapMarket>
  <CapacitySystem >
    <Variable> <NAME> NStep </NAME> <VALUE> 21 </VALUE> </Variable>
    <Variable> <NAME> ItStepUp </NAME> <VALUE> 0,10,20,30,40,50,60,70,80,90,100,0,0,0,0,0,0,0,0,0,0 </VALUE> </Variable>
    <Variable> <NAME> ItStepDown </NAME> <VALUE> 0,0,0,0,0,0,0,0,0,0,10,20,30,40,50,60,70,80,90,100 </VALUE> </Variable>
    <Variable> <NAME> LControlAll </NAME> <VALUE> T </VALUE> </Variable>
    <Variable> <NAME> ModNr </NAME> <VALUE> 112 </VALUE> </Variable>
    <Variable> <NAME> ModNr </NAME> <VALUE> 115 </VALUE> </Variable>
    <Variable> <NAME> ModNr </NAME> <VALUE> 110 </VALUE> </Variable>
    <Variable> <NAME> ModNr </NAME> <VALUE> 119 </VALUE> </Variable>
    <Variable> <NAME> Column </NAME> <VALUE> 1 </VALUE> </Variable>
  </CapacitySystem>
  <CapacityModule MODULNR="111">
    <Variable> <NAME> LastWeekCap </NAME> <VALUE> 20,20,0 </VALUE> </Variable>
    <Variable> <NAME> LastWeekCap </NAME> <VALUE> 30,10,10 </VALUE> </Variable>
    <Variable> <NAME> LastWeekCap </NAME> <VALUE> 52,20,0 </VALUE> </Variable>
    <Variable> <NAME> MinProduction </NAME> <VALUE> 5 </VALUE> </Variable>
    <Variable> <NAME> Column </NAME> <VALUE> 1 </VALUE> </Variable>
  </CapacityModule>
  <CapacityModule MODULNR="113">
    <Variable> <NAME> LastWeekCap </NAME> <VALUE> 52,20,0 </VALUE> </Variable>
    <Variable> <NAME> Column </NAME> <VALUE> 3 </VALUE> </Variable>
  </CapacityModule>
</CapacityMarket>

```

### 3 Specification of prices in different markets

#### 3.1 Prices for Electric Energy

Here we explain how to specify prices for electric energy, i.e. for those markets where the quantity of the product is measured in MWh. This can typically be day-ahead market (such as Nord Pool spot), intraday market (such as Elbas), and markets for providing balancing energy in real time (such as Statnett's regulating power market). For such markets, prices shall be specified as price series in ProdRisk. The specification of price series to ProdRisk is described in the EOPS (no: Vansimtap) user manual (version 9.6).

One price series must be specified for each market type to be included in the analysis, e.g. one for the day-ahead market and one for the intraday market.

#### 3.2 Prices for power reserves

Here we explain how to specify prices for reserve power, i.e. for those markets where the quantity of the product is measured in MW. The name of the file containing power reserve prices is specified in the input file MULTIMARKET.XML, cf. variable NamePowerPrice. Figure 1 shows part of an example file.

Power reserve prices is an optional input, and all power reserve prices are set to zero if the corresponding file do not exist.

It is possible to include several sets of prices in the specified file, but only two of them are used. Based on COLUMN variable in <CapacitySystem> and <CapacityModule> section in MULTIMARKET.XML, it is possible to change what series that is used. Generally the price series is in pairs where first column is upward regulation price in [€/MW] or [currency/MW], and second column is downward regulation prices. It is hourly time resolution on these inputs, and one have to provide prices at least for 52 weeks.

In the first line of the price-file (cf. example in Figure 1), one specifies how many price series that exist in the file (e.g. the number of columns), and for how many weeks prices are specified for. In the example in Figure 1 there are 6 price series and 52 weeks. Comma (,) and dot (.) are used as column- and decimal-separators respectively.

The first row give prices for all reserve markets (separately for up- and down regulation). The first column gives prices for one of the reserve markets for all hours in the planning period. First 168 values for week 1, then 168 values for week 2 and so on. Reserve price values are not

provided per climate year; there is only one value for each hour in the planning period. This can be interpreted as the expected value for reserve prices in different weeks.<sup>3</sup> The number of rows in our example is therefore 52 weeks \* 168 hours/week plus the first line.

```

6,52,,,,
18.9478,1.7945,0.0043,0.0000,0.0000,0.0013
20.3030,1.4915,0.0000,0.0000,0.0000,0.0000
20.8870,0.8365,0.0000,0.0000,0.0000,0.0000
21.2878,1.3213,2.1520,0.0000,0.0000,0.0000
21.2303,1.5633,1.9935,0.0000,0.0000,0.0983
22.4085,1.4288,0.0000,0.0000,0.0000,0.0000
22.5530,0.9140,0.0095,0.0000,0.0000,0.0000
22.2190,2.8803,0.0000,0.0000,0.0000,0.0000
23.7645,4.5408,1.4795,0.0000,0.0000,0.0000
22.7615,4.3645,2.3683,0.0000,0.0000,0.0000
23.3280,1.0783,1.9478,0.0000,0.0000,0.0000
22.3645,1.2758,1.8528,0.0000,0.0000,0.0000

```

**Figure 1 Example of power prices series. Shows first 12 hours.**

---

<sup>3</sup> It would be possible to implement different reserve price values for the different climate scenarios in the inputs. However, to avoid deterministic within-week allocation of capacity, one need to avoid scenario specific values for the amount of reserves supplied.

## 4 Results files

### 4.1 Overview of output files

This prototype uses the same results file as EOPS and ProdRisk version 9.6. See corresponding user manuals for EOPS and ProdRisk for how to extract results available through the ordinary result programs. In addition, there are four new output files that will be explained in the following.

The new output files are:

- IncomeMultiMarket.csv
- ReservedPower.csv
- Production.csv
- Reservoir.csv.

The two last files are optional output files and will not be written unless variables LWriteProduction and LWriteReservoir are set to T (for true), cf. Table 1. In the following we will explain the content of each output file.

In the current version, the new output files should be opened in a text editor with unlimited row length (e.g. Notepad +) or with the fixed width option when choosing text to columns in Excel. length when opened in Excel.

### 4.2 IncomeMultiMarket.csv

The file IncomeMultiMarket.csv gives an overview of income in the different market, weeks and for different combinations of reserve power amounts that have been assessed. The start of the file (first rows, first columns) are shown in Figure 2.

The first lines show the results for each market in the first simulated week. Thereafter, below this, results are shown for the second week and so on. In our example, there are three energy markets (MWh): DA (day-ahead), DA15 (an intraday market), and RK (regulating power market, real time balancing). The names, sequence of markets and prices are taken from the input files. The corresponding income from each market type in the first simulated week is 3.658, 4.443, and 2.979 million respectively. Those are average numbers over all simulated climate years. For capacity markets the income is specified in category "PowerSystem" and "CapacityModule". The former is reserve premium for reserves specified for the whole simulated system, whereas the latter is reserve premium for reserves specified for individual modules. The latter category is not displayed in Figure 2 since no reserves was defined for specific modules in our example.

Week	Market name	Avg. income [Mill/pa]			
1	DA		3.658		3.658
1	DA15		4.443		4.130
1	RK		2.979		3.333
1	PowerSystem		0.000		0.000
1	Total		11.080		11.121
1	PI [€/MW]-DA	0.000	0.000	0.000	0.000
1	PI [€/MW]-DA15	0.000	0.000	-0.103	0.000
1	PI [€/MW]-RK	0.000	0.000	0.000	0.000
1	Power tested [MW]	0.000	0.000	137.102	0.000
2	DA		3.791		3.789
2	DA15		8.386		7.943
2	RK		3.324		3.766
2	PowerSystem		0.000		0.000
2	Total		15.502		15.498
2	PI [€/MW]-DA	0.000	0.000	-0.001	0.000
2	PI [€/MW]-DA15	0.000	0.000	-0.154	0.000
2	PI [€/MW]-RK	0.000	0.000	0.000	0.000
2	Power tested [MW]	0.000	0.000	137.252	0.000

**Figure 2 Example of IncomeMultiMarket.csv, first rows and columns**

The row "Total" is the sum of income from all the markets. It also includes the value of changed reservoir levels (relative to the first simulated combination for reserve power to be evaluated), but in our methodology this value is zero as the operation in all cases will be determined by prices in the final market (RK in our case).

The following lines below "Total" (starting with PI) shows the dual-values (also called shadow prices) for capacity constraints in each energy market, both maximum constraint due to available capacity (shown first) and minimum constraint due (e.g. due to supply of negative reserves, or zero). Therefore, there are two values / columns for the dual values for each value of the income in the different markets. The dual variables for the available capacity are zero or negative because the optimization problem is set up as a cost-minimization.

Finally, the last line in Figure 2 shows the reserved capacity for upward regulation (mentioned first) and for downward regulation. The first combination to be tested in our example is zero reserved capacity. The shown value is in MW rather than percent (reserves are specified as percent in inputs). Reserves specified on individual modules are not included in this value.

The following columns show results for the other alternatives specified for reserved capacity, one by one. Second alternative to be evaluated is the supply of 137.102 MW reserves for upward regulation in week 1, cf. Figure 2. The value is slightly different for week 2 because the specified available capacity in ProdRisk inputs is different for week 2. As shown by the results, the capacity reservation has not impact on the possible supply in the day-ahead market in week 1. However, the supply for the intraday market is constrained in some cases, and thus leads to a reduced income from this market (from 4.443 to 4.130), and a dual variable (-0.103) for the available capacity in the intraday market for week 1. On the other hand, there is more capacity available for supply to the

regulating power market, thus the income in this market increase from 2.979 to 3.333 M in the first week. Thus, even though the price for reserve power (upward regulation) is set to zero for the first week in this example, the total income from all markets increase from 11.080 to 11.121. Therefore, the algorithm will hold back capacity day-ahead and intraday. The following columns at the right (only a part of the file is shown) will identify which combination gives highest total income in total, and this alternative is selected.

At the bottom of the file the yearly<sup>4</sup> income is shown per market, cf. Figure 3. Results are shown for the first tested reserve combination (which often can be no capacity reservation), and for the optimal / best combination. Again, values are average over simulated climate years. Negative values for RK shows that the extra income through upward regulation has been less than the lost income/expense through negative regulation.

In our example, the total profits increase by 65 M per year (from 807 to 872) through the optimization of reserve capacity (MW), of which 11 M is capacity payment. The rest of the extra profits comes from the optimization of the amount of capacity that is available for the different energy markets (MWh), including the "RK" market.

Sum	Market name	Avg inc[Mill/year]Iter=1	Avg inc[Mill/year]BestIt
0	DA	566.008	413.949
0	DA15	359.979	263.272
0	RK	-118.517	183.755
0	PowerSystem	0.000	11.860
0	Total	807.470	872.835

**Figure 3 Example of IncomeMultiMarket.csv, last rows**

<sup>4</sup> Yearly in series simulation. In parallel simulation values shows results for the number of weeks in one simulated scenario, which can be shorter or longer than a year.

### 4.3 ReservedPower.csv

This file shows the selected / best power reservation (upward and downward) for each week. All values are in [MW].

### 4.4 Production.csv

Production file shows production in [MW] for all hydro power plants, markets and time step. See example in Figure 4. The first row identifies the included modules. In the different columns, results are shown for the produced amount in the mentioned modules. First results for the first energy market, then for the second (further to the right in the file, not shown in the figure), and so on.

Each row represent one time step. First results for the first simulated week in the first climate scenario (168 values if hourly resolution is applied). Then the second week, and so on. When results for all weeks in the first climate year has been shown, results from the second climate year follows.

11507	11510	11512	11549	11540	11527	11525	11505	11503
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	
9.00	1.21	0.00-1000.00	0.00	23.11	0.00	80.68	99.34	

**Figure 4 Example of Production.csv**

### 4.5 Reservoir.csv

Reservoir.csv includes reservoir level in [Mm3] for all modules for all time steps. Modules are identified in the first row, and values are shown in the different columns. This file does not have a market dimension, since there will be only one actual operation of the system in one given week/scenario.

Each row represent one time step. First results for the first simulated week in the first climate scenario (168 values if hourly resolution is applied). Then the second week, and so on. When results for all weeks in the first climate year has been shown, results from the second climate year follows.

11506	11510	11512	11541	11549	11548
12.30	11.34	40.47	0.07	276.28	50.80
12.30	11.34	40.48	0.08	276.79	50.78
12.30	11.34	40.49	0.08	276.80	50.78
12.31	11.34	40.50	0.08	276.80	50.78
12.31	11.35	40.51	0.09	276.80	50.79
12.31	11.35	40.51	0.09	276.80	50.79
12.31	11.35	40.52	0.10	276.80	50.79
12.31	11.35	40.53	0.10	276.75	50.79

**Figure 5 Example of Reservoir.csv**

## 5 Running the model

Running the model is the same as the operational 9.6 version of ProdRisk. The only change is that the multimarket functionality is utilized if the file MultiMarket.xml exist.

### References

- [1] Wolfgang, O., Henden, A. L., Belsnes, M. M., Baumann, C., Maaz, A., Schäfer, A., Moser, A., Harasta, M., Døble, T. (2015), "Scheduling when reservoirs are batteries for wind- and solar-power", Energy Procedia, Vol 87, pp. 173 – 180.
  
- [2] Wolfgang, O., Henden, A. L., "Hydropower scheduling for multiple power markets", *forthcoming*.



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