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– The Hydropower, Geothermal and Environmental Energy Component –

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INOLA-Technical Release No. 7:	*INOLA Software Documentation. The Energy Management Component*
INOLA-Technical Release No. 8:	*INOLA Software Documentation. The Investment Cost Component*

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BAT Battery storage component

BUF Buffer Storage component

CHEM Hydrogen and methane storage component

1 The Hydropower Component

The hydropower component determines the electrical energy production of hydropower plants. It is assumed that the hydro power plants are operated independently from the energy market.

Two different model modes are implemented in the energy model of PROMET: The first mode considers the whole hydrological system and therefore needs a complete simulation of the water flows within the involved catchments. A detailed description of the hydrological model is given in WILLEMS, et al. (2007). This mode does not include the dynamic decision-making about the new construction or refurbishment of hydro power plants based on economic criteria.

The second mode can be applied without the requirements of hydrological modelling. The electrical energy generation of the hydropower plants is given in the input files so that the hydrological system does not have to be modelled.

1.1 General equations

In case the hydrological system is simulated the hourly production of the hydropower plants is calculated as described in WILLEMS, et al. (2007).

The second mode of the hydropower model has to be activated in the SEM-File of the Storage Management component (see Technical Release No. 7, Chapter 2). The energy generation from hydropower plants is based on several hourly input files as explained in Chapter 1.3. The first input file contains the sum of the hourly production from the existing plants from three different districts. The second file contains the hydro power plants relevant for the investment calculation and the potential generation obtained from refurbishment or new construction. The modelling of the decision about the new construction or refurbishment is given in Technical Release No 8.

In case the hydrological processes are not modelled, the hourly energy production is calculated as the sum of the running hydropower plants according to Equation (1).

$$E_{HPO,tot} = \sum_{i=1}^{3} E_{HPO,i} \cdot 1000 + \sum_{NBP=1}^{NBP_{max}} E_{NBP} \cdot 1000 \qquad (1)$$

with:

$E_{HPO,tot}$	=	*Total energy production of the hydropower*	*[kWh]*
E_i	=	*Hydropower production of administrative district i*	*[MWh]*
NBP	=	*Number of the newly constructed or refurbished plants*	*[-]*

NBP_{max}	=	*Current maximum number of newly constructed or refurbished plants*	*[-]*
ENBP	=	*Hydropower production of plant NBP*	*[MWh]*

1.2 Pre-processing

In the case the first mode of the hydropower model is used, a detailed description of the pre-processing is given in WILLEMS, et al. (2007). If the second mode is activated, the pre-processing includes the determination of the hourly production rates. This has to be done by a separate run, which contains the modelling of the flow regimes under the hydrological boundary conditions. The pixel of the plants can be determined by overlaying the GIS-Layer with the mask of the model region.

1.3 Input Data and Format

The hydropower setup file, which includes the input for potential and existing hydropower plants, contains the following sections:

- [General]:

Table 1-1: Description of the input-file for the Hydropower Plant Model, Section General

Input Parameters	Description	Unit	Data format
HPOName	Name of the Hydro Power Plant	[-]	character
HPOID	ID-Number of the Hydro Power Plant	[-]	integer
HPOProxel	Pixel of the Hydro Power Plant	[-]	integer

- [HydropowerModel]:

Table 1-2: Description of the input-file for the Hydro Power Plant Model, Section HydropowerModel

Input Parameters	Description	Unit	Data format
HPOStartyear, HPOStartMonth, PSPStartDay	Start time of the Hydro Power Plant	[-]	integer
HPO_MaxMW	Maximum performance of the Hydro Power Plant	[MW]	real
Productivity	Productivity of the Hydro Power Plant	[-]	real
ID_Area	ID number of the area	[-]	integer

Example setup for the Hydro Power Plant:

```
[General]
ObjectType              HydropowerModel
HPOName                 E2104101S16000000000036877500001
HPOID                   7
HPOProxel               160         659
[end]

[HydropowerModel]
HPOStartYear            2012
HPOStartMonth           1
HPOStartDay             12
HPOMaxMW                0.007
Productivity            0.48
ID_Area                 1
[end]
```

Figure 1-1: Example of the input file for the Hydro Power Plant Model

The production of the hydro power plants, which are not analysed in detail, is cumulated on district scale and formatted in list form. The input files have to be given separately for each of the simulated years under the name Hydro_Year.txt and placed in one folder.

```
Year Month Day Hour ID1    ID2    ID3
2011 1     1   0    93.538  0.202  0.861
2011 1     1   1    82.248  1.386 14.954
2011 1     1   2    82.879  2.694 24.117
…
```

Figure 1-2: Example of the input file for the hourly electrical energy production from the hydro power plants

The hourly electrical energy production of the hydro power plants specified in the input file is formatted in a list separately for each simulated year. The separate consideration of a maximum of 28 plants is possible. The input files have to be given separately for each of the simulated years under the name Hydro_YearNBP.txt and placed in one folder.

```
HPO1  HPO2  HPO3  HPO4  HPO5  HPO6  HPO7  HPO8  HPO9  HPO10 HPO11 HPO12 HPO13
0.009 0.003 0.005 9.317 0.001 0.002 0.002 0.017 0.102 0.120 0.002 0.005 0.011
0.949 0.137 0.012 8.186 0.001 0.010 0.032 0.026 0.134 0.021 0.079 0.169 0.122
0.949 0.530 0.017 8.142 0.010 0.143 0.099 0.000 0.940 0.170 0.117 0.035 0.027
…
```

Figure 1-3: Example of the input file for hourly electrical energy production from the specified hydro power plants

1.4 Output

The output of the hydro power plant model includes the electrical energy production in MWh on hourly resolution.

2 The Geothermal and Environmental Energy Component

The geothermal and environmental energy component determines the thermal energy production of brine-water and air-water heat pumps, which represent approximately 96 % (brine-water: 26 %, air-water: 70 %) of all heat pumps in Germany (BWP 2015), as well as the thermal and electrical energy production of deep geothermal plants. It is assumed that brine-water and air-water heat pumps can be installed on residential and non-residential buildings and are always coupled to a buffer storage system (see *INOLA-Technical Release No. 6: The Energy Storage Component*). The component does include the possibility for dynamic decision-making about the new construction or refurbishment of deep geothermal plants based on economic criteria (see *INOLA-Technical Release No. 8: The Investment Cost Component*).

2.1 General equations

2.1.1 Brine-Water and Air-Water Heat Pumps

The approach for brine-water and air-water heat pumps bases on the Coefficient of Performance (COP). The COP describes the ratio between the thermal output of the heat pump and the amount of electric power needed to produce this thermal output and therefore reflects the heat pump's efficiency. On annual basis it is represented by the annual COP, which resembles the system efficiency of solar thermal plants and is used in this approach. The current thermal energy production and related electricity consumption of the heat pumps are calculated as follows:

$$H_{HP} = P_{th}$$
$$C_{HP} = \frac{P_{th}}{annCOP} \tag{2}$$

mit:

H_{HP}	=	*Thermal energy production of the heat pump*	$[kWh]$
C_{HP}	=	*Electrical energy consumption of the heat pump*	$[kWh]$
P_{th}	=	*Thermal capacity of the heat pump*	$[kW]$
$annCOP$	=	*Annual Coefficient of Performance*	$[-]$

2.1.2 Deep Geothermal Plants

The simulation of deep geothermal plants follows a very simple approach. Deep geothermal plants are independent of meteorological variability and contribute to base load supply. It is assumed that they are operated constantly at full load (Equation (3)).

$$E_{DGT} = P_{DGT,el}$$
$$H_{DGT} = P_{DGT,th} \tag{3}$$

with:

E_{DGT}	=	*Electrical energy production of the deep geothermal plant*	*[kWh]*
$P_{DGT,el}$	=	*Electric capacity of the deep geothermal plant*	*[kW]*
H_{DGT}	=	*Thermal energy production of the deep geothermal plant*	*[kWh]*
$P_{DGT,th}$	=	*Thermal capacity of the deep geothermal plant*	*[kW]*

2.2 Pre-processing

The pre-processing includes the identification of all existent heat pumps and deep geothermal plants within the region under assessment with their exact positions and technical parameters. Positions as well as rated output of devices within the EWO region were taken from BAYSTMWI (2015) and ENERGYMAP (2015). Annual COP values for heat pumps, their development since 2007 and a projected continuation until 2045 were taken and derived from BWP (2015) as shown in Appendix.

2.3 Input Data and Format

2.3.1 Brine-Water and Air-Water Heat Pumps

The heat pump setup file (*.SGT), which includes the input for future and existing heat pumps, contains the following sections:

- [General]:

Table 2-1: Description of the input-file for the Heat Pump Model, Section General

Input Parameters	Description	Unit	Data format
ObjectName	**Name of the Heat Pump**	**[-]**	**character**
ObjectID	**ID-Number of the Heat Pump**	**[-]**	**integer**
Position-Proxel	**Pixel of the Heat Pump**	**[-]**	**integer**

- [SurfaceGeoModel]:

Table 2-2: Description of the input-file for the Heat Pump Model, Section SurfaceGeoModel

Input Parameters	Description	Unit	Data format
SurfaceGeoYear, SurfaceGeoMonth, SurfaceGeoDay	Installation date of the Heat Pump	[-]	integer
SurfaceGeoType	Type of heat pump; 1: brine-water, 2: air-water	[-]	integer
SurfaceGeoType2	Type of building; 1: residential building, 2: non-residential building	[-]	integer
Rated Output	Thermal capacity of heat pump	[kW]	real
COP	Annual COP value	[-]	real

Example setup for the Heat Pump:

```
[General]
ObjectType              surfacegeo
ObjectName              DEBY_LOD2_4059657
ObjectId                1
Position-Proxel         176         477
[end]

[SurfaceGeoModel]
SurfaceGeoActive        1
SurfaceGeoYear          2007
SurfaceGeoMonth         1
SurfaceGeoDay           1
SurfaceGeoModel         1
SurfaceGeoType          1
SurfaceGeoType2         2
Rated Output            8.527500
COP                     3.25
[end]
```
Figure 2-1: Example of the input file for the Heat Pump Model

2.3.2 Deep Geothermal Plants

The heat pump setup file (*.DGT), which includes the input for potential and existing deep geothermal plants, contains the following sections:

- [General]:

Table 2-3: Description of the input-file for the Deep Geothermal Model, Section General

Input Parameters	Description	Unit	Data format
ObjectName	Name of the deep geothermal plant	[-]	character

ObjectID	**ID-Number of the deep geothermal plant**	**[-]**	**integer**
Position-Proxel	**Pixel of the deep geothermal plant**	**[-]**	**integer**

- [SurfaceGeoModel]:

Table 2-4: Description of the input-file for the Deep Geothermal Model, Section DeepGeoModel

Input Parameters	Description	Unit	Data format
DeepGeoYear, DeepGeoMonth, DeepGeoDay	**Installation date of the deep geothermal plant**	**[-]**	**integer**
NennleistungTherm	**Thermal capacity of the deep geothermal plant**	**[kW]**	**real**
NennleistungElektrisch	**Electric capacity of the deep geothermal plant**	**[kW]**	**real**
productivity	**Expected productivity (only for potential plants, for existing plants the value may be 0)**	**[-]**	**real**

Example setup for the deep geothermal plants:

```
[General]
ObjectType              deepgeo
ObjectName              Holzkirchen
ObjectId                1
Position-Proxel         113         757
[end]

[DeepGeoModel]
DeepGeoActive           1
DeepGeoYear             2019
DeepGeoMonth            3
DeepGeoDay              1
DeepGeoModel            1
NennleistungTherm       24500
NennleistungElektrisch  3400
productivity            0
[end]
```

Figure 2-2: Example of the input file for the Deep Geothermal Model.

2.4 Output

The output of the Geothermal and Environmental Energy Component includes the electrical and thermal energy production of deep geothermal plants as well as the thermal energy production and electrical energy consumption of brine-water and air-water heat pumps in kWh on hourly resolution.

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Appendix

A 1: Annual COP values and projected trends used to simulate brine-water and air-water heat pumps (derived from BWP 2015).

Type of heat pump	Annual COP value [-]			
	2010	2015	2030	2045
Brine-water heat pump	3.4	3.8	4.4	5.1
Air-water heat pump	2.8	3.1	3.6	4