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– The Energy Management 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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AC	Alternative current
BAT	Battery storage component
DFL	Dynamic feed-in limit
FFL	Fixed feed-in limit
HP	Heat pumps/Surface geothermal energy systems
PV	Photovoltaic system
ST	Solar thermal system

1 Introduction

The storage and energy management component includes the description of the operation rules applied to the different storage types. Two levels are divided: The first level is restricted to the domestic scale, which includes automatically operated building-related electrical and heating systems. The second level covers the regional scale, which includes the management of large-scale energy systems by energy suppliers.

The management of the differences of the consumption and production rates determine the energy flows, which are available for the storages. The detailed description of the charging and discharging processes for the different storage types are given in Technical Release No 6.

2 The energy management main component

The energy management component has several tasks. This includes the following three:

- Activation and management of the storage types on domestic and regional scale described in Technical Release No. 6
- Activation of the invest costs calculation for all relevant production and storage types
- Activation of the hydropower component
- Spatially accumulated output of the hourly energy flows for an overview

The management of the storage types includes two system combinations on domestic scale:

- Domestic batteries systems, which are DC-coupled to roof-top mounted PV systems
- Domestic buffer storages, which are coupled to solar thermal plants or heat pumps

The management of the regional storages is categorized into three types:

- Battery systems on neighbourhood-level
- Grid-operated large scale electrical storages like pumped storages, gravity power plants, battery storages, power-to-heat systems, chemical storage systems
- Distributed heat networks

2.1 Input Data and Format

The setup file contains the following sections:

- [General]:

Table 2-1: Description of the input-file for the Energy Management, Section General

Input Parameters	Description	Unit	Data format
SEMProxel	**Pixel of the energy management file**	**[-]**	**integer**
EnergyStorage	**y – Calculation of energy storage systems**	**[-]**	**character**

- [ElecStorage]:

Table 2-2: Description of the input-file for the Energy Management, Section ElecStorage

Input Parameters	Description	Unit	Data format
Pumped Storage Plants	**y - Activation of Pumped Storage Plants**	**[-]**	**character**
Gravity Power Plants	**y - Activation of Gravity Power Plants**	**[-]**	**character**
Battery Storage	**y - Activation of grid operated Battery Storages**	**[-]**	**character**
Dynamic FeedIn-Limit	**y – Consideration of Dynamic Feed-In limits**	**[-]**	**character**
Electric Mobility	**y - Activation of Electromobility component**	**[-]**	**character**

- [HeatStorage]:

Table 2-3: Description of the input-file for the Pumped Energy Management, Section HeatStorage

Input Parameters	Description	Unit	Data format
Buffer Storage	**y - Activation of buffer storages**	**[-]**	**character**
Dist Heat Networks	**y - Activation of distributed heat networks**	**[-]**	**character**
Seasonal Storage	**y - Activation of seasonal storages**	**[-]**	**character**
Power to Heat	**y - Activation of Power to heat systems**	**[-]**	**character**

- [ChemStorage]:

Table 2-4: Description of the input-file for the Pumped Energy Management, Section ChemStorage

Input Parameters	Description	Unit	Data format
H2/CH4 Storage	**y - Activation of chemical storage systems**	**[-]**	**character**

- [ProdHydro]:

Table 2-5: Description of the input-file for the Pumped Energy Management, Section ProdHydro

Input Parameters	Description	Unit	Data format
Hydro Power	**y - Activation of hydro power**	**[-]**	**character**

- [InvestCosts]:

Table 2-6: Description of the input-file for the Pumped Energy Management, Section InvestCosts

Input Parameters	Description	Unit	Data format
Invest Costs	**y - Activation of invest costs calculation**	**[-]**	**character**

- [Eval_Proxel]:

Table 2-7: Description of the input-file for the Energy Management, Section Eval_Proxel

Input Parameters	Description	Unit	Data format
Econs WG	**Electrical energy consumption of the residential buildings per district**	**[kW]**	**Real**
Econs NWG	**Electrical energy consumption of the ITC buildings per district**	**[kW]**	**Real**
Econs Sons	**Electrical energy consumption of miscellaneous per district**	**[kW]**	**Real**
SGeoCons WG	**Electrical energy consumption of residential heat pumps per district**	**[kW]**	**Real**
SGeoCons NWG	**Electrical energy consumption of ITC heat pumps per district**	**[kW]**	**Real**
WCons WG	**Heat energy consumption of residential buildings per district**	**[kW]**	**Real**

WCons NWG	**Heat energy consumption of ITC buildings per district**	**[kW]**	**Real**
GCons WG	**Gas consumption of residential buildings per district**	**[kW]**	**Real**
GCons WG	**Gas consumption of ITC buildings per district**	**[kW]**	**Real**
GCons Sons	**Gas consumption of public buildings per district**	**[kW]**	**Real**
EWindProd	**Electrical energy production from wind plants per district**	**[kW]**	**Real**
ESolPowProd WG	**Electrical energy production from residential solar plants per district**	**[kW]**	**Real**
ESolPowProd NWG	**Electrical energy production from ITC solar plants per district**	**[kW]**	**Real**
ESolPowProd FF	**Electrical energy production from ground mounted solar plants per district**	**[kW]**	**Real**
EDegeoProd	**Electrical energy production from geothermal plants per district**	**[kW]**	**Real**
EBiogasProd	**Electrical energy production from biogas plants per district**	**[kW]**	**Real**
EWoodBHKWprod	**Electrical energy production from wood-fired heating plants per district**	**[kW]**	**Real**
EGasBHKWprod	**Electrical energy production from gas-fired plants per district**	**[kW]**	**Real**
HydroProd	**Electrical energy production from gas-fired plants per district**	**[kW]**	**Real**
WSHeatprod WG	**Heat energy production from domestic solar thermal plants per district**	**[kW]**	**real**
WSHeatprod NWG	**Heat energy production from ITC solar thermal plants per district**	**[kW]**	**real**
WSHeatGedBed WG	**Heat energy consumption from domestic buildings covered with buffer storages and solar thermal plants per district**	**[kW]**	**real**
WSHeatGedBed NWG	**Heat energy consumption from ITC buildings covered with buffer storages and solar thermal plants per district**	**[kW]**	**real**
WSHeatprod FF	**Heat energy production from ground mounted solar thermal plants per district**	**[kW]**	**Real**
WSGeoprod WG	**Heat energy production from domestic surface geothermal systems per district**	**[kW]**	**real**
WSGeoprod NWG	**Heat energy production from ITC surface geothermal systems per district**	**[kW]**	**real**
WSGeoGedBed WG	**Heat energy consumption from domestic buildings covered with buffer storages and surface geothermal systems per district**	**[kW]**	**real**

WSGeoGedBed NWG	Heat energy consumption from ITC buildings covered with buffer storages and surface geothermal systems per district	[kW]	Real
WDGeoProd NWN	Heat energy production from deep geothermal systems coupled to distributed heat networks per district	[kW]	real
WHolzGedBed WG	Heat energy consumption from domestic buildings covered wood-fired heating systems per district	[kW]	real
WHolzGedBed NWG	Heat energy consumption from ITC buildings covered wood-fired heating systems per district	[kW]	real
WGasGedBed WG	Heat energy consumption from domestic buildings covered gas-fired heating systems per district	[kW]	real
WGasGedBed NWG	Heat energy consumption from ITC buildings covered gas-fired heating systems per district	[kW]	Real
WBiogas NWN	Heat energy production from biogas plants coupled to distributed heat networks per district	[kW]	real
WHolzBHKW NWN	Heat energy production from wood biomass plants coupled to distributed heat networks per district	[kW]	real
WGasBHKW NWN	Heat energy production from gas plants coupled to distributed heat networks per district	[kW]	real
WGedBed NWN	Heat energy consumption covered by distributed heat networks per district	[kW]	real
GBiogasProd	Gas production from biogas plants per district	[kW]	real

- [EvalS_Proxel]:

Table 2-8: Description of the input-file for the Energy Management, Section EvalS_Proxel

Input Parameters	Description	Unit	Data format
EBattery P WG NWG	Electrical power of the batteries of the residential and ITC buildings	[kW]	real
EBattery LQuat	Electrical power of the batteries of the neighbourhood systems	[kW]	real
EBattery LGS	Electrical power of the grid operated batteries	[kW]	real
EMobilty P	Electrical power of the batteries from electric mobility	[kW]	real
EPSP P	Electrical power of the pumped storage plants	[kW]	real
EGSP P	Electrical power of the gravity storage plants	[kW]	real

EPtH P	**Electrical power of the power-to-heat systems**	**[kW]**	**real**
EPtG P	**Electrical power of the power-to gas systems**	**[kW]**	**real**
EMobility A Cons	**Annual energy demand of electric mobilits**	**[kW]**	**real**
WBuf P WG NWG	**Heat power of the buffer storages of residential and ITC buildings**	**[kW]**	**real**
WBuf P NWN	**Heat power of the buffer storages of distributed heat networks**	**[kW]**	**real**
WSais P	**Heat power of the seasonal storages**	**[kW]**	**real**
WPtH P	**Heat power of the power-to-heat systems**	**[kW]**	**real**
WPtG P	**Heat power of the power-to-gas systems**	**[kW]**	**real**
GPtGP	**Gas consumption/production of the power-to-gas systems**	**[kW]**	**real**

- [EvalD_Proxel]:

Table 2-9: Description of the input-file for the Energy Management, Section EvalD_Proxel

Input Parameters	**Description**	**Unit**	**Data format**
DeltaE nSt	**Electrical energy delta of the region before storage operation**	**[kW]**	**real**
DeltaE BuiSt	**Electrical energy delta of the region after storage operation of build-ings**	**[kW]**	**real**
DeltaE	**Electrical energy delta of the region after operation of all storages**	**[kW]**	**real**
E Curtailment	**Curtailment losses due to export limits of the grids**	**[kW]**	**real**
DeltaW	**Heat energy delta of the region after storage operation**	**[kW]**	**real**
DeltaW NWN	**Heat energy delta of distributed heat networks**	**[kW]**	**real**
DeltaG nSt	**Gas energy delta of the region before storage operation**	**[kW]**	**real**
DeltaG	**Gas energy delta of the region after storage operation**	**[kW]**	**real**
Production CO^2	**CO^2 Production of biogas plants**	**[kW]**	**real**
Consumption CO^2	**CO^2 Consumption of power-to-gas methane plants**	**[kW]**	**real**

- [No_Proxel]:

Table 2-10: Description of the input-file for the Energy Management, Section No_Proxel

Input Parameters	Description	Unit	Data format
Wind	Number of active wind plants per district	[-]	real
SolPow WG	Number of active domestic PV plants per district	[-]	real
SolPow NWG	Number of active ITC PV plants per district	[-]	real
SolPow FF	Number of active ground-mounted PV plants per district	[-]	real
SHeat WG	Number of active domestic solar thermal plants per district	[-]	real
SHeat NWG	Number of active ITC solar thermal plants per district	[-]	real
SHeat FF	Number of active ground-mounted solar thermal plants per district	[-]	real
SGeo WG	Number of active domestic surface geothermal plants per district	[-]	real
SGeo NWG	Number of active ITC surface geothermal plants per district	[-]	real
DGeo	Number of active deep geothermal plants per district	[-]	real
Biogas	Number of active biogas plants per district	[-]	real
WoodBHKW	Number of active wood-fired biomass plants per district	[-]	real
GasBHKW	Number of active gas-fired plants per district	[-]	real
WoodHeat WG	Number of active domestic wood-fired heating systems per district	[-]	real
WoodHeat NWG	Number of active ITC wood-fired heating systems per district	[-]	real
HydroPow	Number of active hydropower plants per district	[-]	real
Bat WG	Number of active domestic battery storage systems per district	[-]	real
Bat NWG	Number of active ITC battery storage systems per district	[-]	real
Bat GS	Number of active grid operated battery storage systems per district	[-]	real
PSP	Number of active pumped storage plants per district	[-]	real

GSP	**Number of active gravity storage plants per district**	**[-]**	**real**
PtG	**Number of active power-to-gas systems per district**	**[-]**	**real**
BUF	**Number of active buffer storage systems per district**	**[-]**	**real**
PtH	**Number of active power-to-heat systems per district**	**[-]**	**real**
SEA	**Number of active seasonal heat storages per district**	**[-]**	**real**
NWN	**Number of active distributed heat networks per district**	**[-]**	**real**
GSP	**Number of active gravity storage plants per district**	**[-]**	**real**
NWN	**Number of active distributed heat networks per district**	**[-]**	**Real**
WG	**Number of domestic buildings per district**	**[-]**	**Real**
NWG	**Number of ITC buildings per district**	**[-]**	**real**

- [PerCap_S]:

Table 2-11: Description of the input-file for the Energy Management, Section PerCap_S

Input Parameters	**Description**	**Unit**	**Data format**
Per Bat	**Total performance of the batteries of the region**	**[kW]**	**real**
Cap Bat	**Total capacity of the batteries of the region**	**[kW]**	**real**
Per PSP	**Total performance of the pumped storage plants of the region**	**[kW]**	**real**
Cap PSP	**Total capacity of the pumped storage plants of the region**	**[kW]**	**real**
Per GSP	**Total performance of the gravity storage plants of the region**	**[kW]**	**real**
Cap GSP	**Total capacity of the gravity storage plants of the region**	**[kW]**	**real**
Per PtG	**Total performance of the power-to-gas systems of the region**	**[kW]**	**real**
Cap PtG	**Total capacity of the power-to-gas systems of the region**	**[kW]**	**real**
Cap Buf	**Total capacity of the buffer storages of the region**	**[kW]**	**real**

Per PtH	**Total performance of the power-to-heat systems of the region**	**[kW]**	**real**
Cap Sea	**Total capacity of the seasonal heat storages of the region**	**[kW]**	**real**

Example setup for the Energy Management File:

```
[General]
ObjectType              SEM
Pixel Delta             223      232
EnergyStorage           y
[end]

[ElecStorage]
PumpedStoragePlants     y
GravityPowerPlants      y
BatteryStorage          y
DynamicFeedIn_Limit     n
Electromobility         y
[end]

[HeatStorage]
BufferStorage           y
HeatNetworks            y
SeasonalStorage         y
Power to Heat           y
[end]

[ChemStorage]
H2/CH4-Storage          y
[end]

[ProdHydro]
HydroPower              y
[end]

[InvestCosts]
InvestCosts             y
[end]

[Eval_Proxel]
Econs WG                180   550     170   740    170   270
…
[end]

[EvalS_Proxel]
EBat Leistung HH        460   500
…
[end]

[EvalD_Proxel]
DeltaE ohne Speicher    461   505
…
[end]

[No_Proxel]
Wind                    183   558     173   748    173   278
…
```

```
[end]
Saisonale Wärmespeicher, Pufferspeicher

[PerCap_S]
Per Bat               186   556     176   746    176   276
…
[end]
```

Figure 2-1: Example of the input file for the Energy Management file

2.2 Output

Layer 1045 contains the results from the consumption, production and storage components in short form specified in the input blocks for [Eval_Proxel], [EvalS_Proxel], [EvalD_Proxel], [No_Proxel], and [PerCap_S].

3 The storage operation on domestic scale

Two storage systems are managed on domestic scale:

- Battery devices which are coupled to roof-top mounted PV-systems in AC-mode
- Buffer storage tanks, which supply the households

3.1 The management of domestic battery systems

The battery systems, which are coupled to PV systems, are managed individually for each system. Only the output is aggregated to pixel scale. The assignment of the PV-systems to their storages is specified in the input file of the batteries by their ID-number and consistent pixel numbers.

3.1.1 General equations

First, the energy delta on domestic scale is calculated for all households having a battery storage devices coupled to PV-systems at each time step.

Equation (1) shows the determination of the energy delta per building from the energy production of the PV-system and the consumption consumer type, which is specified in the input file for the batteries. It is assumed that the PV-system is directly coupled to the battery storage devices, so that the produced electrical energy does not need to be converted to DC-power.

$$\Delta E_B = \frac{E(CT)}{n_B(CT)} - \frac{P_{PV}(B)}{\eta_{CT}} \tag{1}$$

with:

ΔE_B	=	*Electrical energy delta of building B*	*[kW]*
$E(CT)$	=	*Consumption of consumer type CT*	*[kW]*
$n_B(CT)$	=	*Amount of buildings of consumer type CT on the pixel*	*[-]*
$P_{PV}(B)$	=	*Energy Production of the coupled PV-system of building B (already converted to DC)*	*[kW]*
η_{CT}	=	*Efficiency of the PV-converter*	*[-]*

Three charging and discharging strategies for the management of the batteries are implemented, which are specified in the input file of the batteries: A detailed description of the charging and discharging process is given in Technical Release No. 6 chapter 4.

1. Maximization of the self-consumption rate:
   - $\Delta E_B > 0$: Discharging of the battery
   - $\Delta E_B < 0$: Charging of the battery
2. Fixed feed-in limit of 70% of the PV of the PV-system (FFL) :
   - $\Delta E_B > 0$: Discharging of the battery
   - $\Delta E_B < 0$: Charging of the battery, if $\Delta E_B > FFL$
3. Daily dynamic feed-in limit (DFL):
   - $\Delta E_B > 0$: Discharging of the battery
   - $\Delta E_B < 0$: Charging of the battery, if $\Delta E_B > DFL$

The remaining energy delta is fed into the grid in case of an energy excess or supplied by the grid in case of a deficit.

3.1.2 Output

The output includes the residual loads after storage operation and feed-in limitations

3.2 The management of the domestic buffer storage systems

The buffer systems, which are coupled to the domestic heating, are managed individually for each system at each time step. Only the output is aggregated to pixel scale. The assignment of the heating systems to their buffer storages is specified in the input file of the buffer storages by the category, their ID-numbers and consistent pixels.

3.2.1 General equations

Two heating options are implemented that can be coupled to buffer storages for the decentral supply of thermal energy:

- Solar thermal systems ST
- Heat pumps/Surface geothermal energy systems HP

At every time step the thermal energy delta is calculated first according to Equation (2) similarly for both system combinations.

$$\Delta H_B = \frac{H(CT)}{n_B(CT)} - P_{ST/HP}(B) \qquad (2)$$

with:

ΔH_B	=	*Thermal Energy delta of building B*	*[kW]*
$H(CT)$	=	*Heat consumption of consumer type CT*	*[kW]*
$n_B(CT)$	=	*Amount of buildings of consumer type CT on the pixel*	*[-]*
$P_{ST/HP}(B)$	=	*Energy Production of the coupled heating system of building B*	*[kW]*

The charging and discharging process of the buffer storage system depends on the sign of the delta:

- $\Delta H_B > 0$: Discharging of the buffer storage
- $\Delta H_B < 0$: Charging of the buffer storage

The charging process is started as soon as the temperature of the produced thermal energy increases the mean temperature of the buffer storage by 7 °C. If the solar thermal plant or heat pump is already running, a minimum difference of 3 °C is needed between production and buffer storage temperature for the continuation. The determination of the minimum energy difference is given in Technical Release No. 6 Equation 19.

As described in Technical Release No. 6 Chapter 6.1.1, the buffer tanks on domestic scale have to keep a minimum temperature to secure the supply with heat energy or the hygienic demands in case of drinking water supply. If the energy content of the buffer tanks fall below this threshold, the associated heating system is activated. For buffer storages coupled to solar systems, it is assumed that the difference to the minimum energy threshold is secured by pellet-vessels described in Technical Release No. 5 chapter 4.1.2.

The buffer tanks combined with surface geothermic systems secure their thresholds by managing the operation of the heat pumps. When the energy content of the buffer tank falls below the minimum temperature threshold due to heat consumption, the surface geothermal energy system is activated and operated at rated power (see Technical Release No. 3 Chapter 2). As soon as the buffer storage reaches the maximum thermal energy content again, the heating system is shut off in the time step.

4 The storage operation on regional scale

Three storage systems are operated of the regional scale:

- Battery systems on neighbourhood-level
- Grid-operated large scale electrical storages like pumped storages, gravity power plants, battery storages, power-to-heat systems, chemical storage systems
- Distributed heat networks

4.1 The management of battery systems on neighbourhood level

This model manages the batteries, which are driven by an energy neighbourhood or community. It allows a flexible set-up the number of connected buildings, and the amount of coupled PV systems. It is assumed the grid between the consumers, the battery and PV plants is in AC mode, so that the power flows have to be converted via inverter for the charging and discharging processes of the battery. Further losses from transmissions in the grids are not considered.

4.1.1 General equations

The battery systems, which are operated on neighbourhood level, are dependent on

The energy consumption is calculated as the hourly energy demand of the buildings connected to the community battery (see Equation (3)).

$$C_{QBat} = \sum C_{D,QBat} + \sum C_{ITC,QBat} \tag{3}$$

with:

C_{QBat}	=	*Energy consumption of the buildings connected to the community battery*	*[kW]*
$C_{D,\ QBat}$	=	*Energy consumption of the residential buildings connected to the community battery*	*[kW]*
$C_{ITC,\ QBat}$	=	*Energy consumption of the ITC buildings connected to the community battery*	*[kW]*

The production is calculated from the performance of the PV systems specified in the Production Unit as shown in Equation (4).

$$PV_{QBat} = \sum P_{PV,QBat} \tag{4}$$

with:

PV_{QBat}	=	*Energy production of the PV-systems connected to the community battery*	*[kW]*
$P_{PV,\ QBat}$	=	*Energy consumption of the residential buildings connected to the community battery*	*[kW]*

The energy delta is determined as the difference between consumption and production (see Equation (4)). The energy delta is one of the limiting factors for the charging and discharging quantities of the community battery storage. A detailed description of the battery storage model is given in Technical Release No 6 chapter 4.

$$\Delta E_{QBat} = C_{QBat} - PV_{QBat} \tag{5}$$

with:

ΔE_{QBat}	=	*Energy delta for the battery storage operation*	*[kW]*

The energy delta that cannot be covered by the battery is supplied by or fed into the grid.

$$\Delta E_{Grid} = \Delta E_{Grid} - P_{QBat} \tag{6}$$

with:

ΔE_{Grid}	=	*Energy delta fed into or supplied by the grid*	*[kW]*
P_{QBat}	=	*Charging/Discharging Power of the battery*	*[kW]*

4.1.2 Input data and format

The setup file for the management of the neighbourhood batteries contains the following sections:

- [General]:

Table 4-1: Description of the input-file for the management of battery systems on neighbourhood level, Section General

Input Parameters	Description	Unit	Data format
BatName	**Name of the neighbourhood battery**	**[-]**	**character**
BatID	**ID number of the neighbourhood battery**	**[-]**	**integer**

- [ConsumptionUnits]:

Table 4-2: Description of the input-file for the management of battery systems on neighbourhood level, Section ConsumptionUnits

Input Parameters	Description	Unit	Data format
NoBuildings	**Number of pixels with buildings connected to the battery community**	**[-]**	**integer**
Pixel, NoWG, NoNWG, NoSons	**Pixel with number of domestic and ITC buildings, number of miscella-neous**	**[-]**	**Integer, integer, in-teger, integer**

- [ProductionUnits]:

Table 4-3: Description of the input-file for the management of battery systems on neighbourhood level, Section ProductionUnits

Input Parameters	Description	Unit	Data format
NoPV	**Number of entries for coupled PV systems**	**[-]**	**integer**
PVName	**Name of coupled PV system**	**[-]**	**Character**
PVNo	**ID number of the coupled PVsystem**	**[-]**	**Integer**

Example setup for the management of battery systems on neighbourhood level:

```
[General]
ObjectType              bat
BatName                 E31177010000000005007724610-00001
BatID                   1133
[end]

[ConsumptionUnits]
NoBuildings             359
217          73            1           0           0
217          74            3           0           0
[end]

[ProductionUnits]
Anzahl der Anlagen      1
Prodtype                solarp
PVName                  E31177010000000005007724121-00
PVNo                    21503
[end]
```

Figure 4-1: Example of the input file for management of battery systems on neighbourhood level

4.1.3 Pre-processing

The pixel and ID numbers of the PV systems must strictly correspond to the information given in the input file for the solar energy component. The buildings connected to the heat networks have to be read in in the input files of the energy consumption component.

4.1.4 Output

The output includes the energy delta that is not covered, and fed into respectively supplied by the grid.

4.2 The management of regional electrical storage systems

The grid-operated electrical energy systems are managed according the regional demand and excess to balance the regional differences between consumption and production. This means that the supra-regional management, which consider the total electrical market, are not integrated. This includes aspects like grid-services, control power or electricity trade. The condition of the total electricity system is only indirectly represented by the electricity price. In case of an energy surplus after the total storage operation, the excess power is available for the further hourly consumption of the electric cars.

Apart from these limitations, regional grid-related aspects like bottlenecks within the region, different efficiencies in the transmission, and losses in the conversion between different grid levels are neglected.

4.2.1 General equations

First, the energy delta is calculated on regional scale for all production, consumption components at each time step.

Equation (1) shows the determination of the hourly regional energy consumption. As the energy demand of buildings with PV coupled batteries is already included in the domestic energy deltas, this amount of hourly consumption is excluded.

$$E_{Cons,R} = \sum_{CT=1}^{3} E_{B,h}(CT) + E_{Msc,h} + \mathrm{SGHP(HH)} + \mathrm{SGHP(NWG)} - B_{C,Bat} - C_{QBat} \tag{7}$$

with:

$E_{Cons,R}$	=	*Electrical energy consumption of region R*	*[kW]*
$E_{B,h}(CT)$	=	*Hourly consumption of consumer type CT*	*[kW]*
SGHP	=	*Electrical energy consumption of heat pumps*	*[kW]*

$B_{C,Bat}$	=	*Consumption of buildings with residential PV-coupled batteries*	*[kW]*

The regional energy production is calculated as the sum of all production types. As the energy production of PV systems coupled to residential batteries is already included in the domestic energy deltas, this amount of hourly production is excluded.

$$\begin{aligned} E_{Prod,R} = {} & Wprod + SolPHH + SolPGHD + SolPFF + DgeoProd \\ & + BiosgasProd + GPLProd + BHSprod + Wk - B_{PV,Bat} \\ & - PV_{QBat} \end{aligned} \tag{8}$$

with:

$E_{Prod,R}$	=	*Electrical energy production of the region*	*[kW]*
$B_{PV,Bat}$	=	*Production of buildings with residential PV-coupled batteries*	*[kW]*

The energy delta is calculated as the difference between production and consumption.

$$\Delta E_{E,R} = E_{Prod,R} - E_{Cons,R} + \Delta E_{B,CBat} + \Delta E_{QBat} \tag{9}$$

with:

$\Delta E_{E,R}$	=	*Electrical energy delta of the region*	*[kW]*
$\Delta EB_{,CBat}$	=	*Electrical energy delta of buildings with residential PV-coupled batteries*	*[kW]*

The operation of the storages is carried out in hierarchical order according to the typical storage durations:

- Large-scale batteries for grid operation
- Power-to-Heat systems
- Power-to-Gas conversion systems and storages
- Gravity storage plants
- Pumped-storage plants

If the economic model is activated, the possible charging hours of batteries are limited to the two hours of the day with the lowest energy price, the possible charging hours of power-to-gas systems to the six hours of the day with the lowest energy price.

The regionally managed storage systems are charged when $\Delta E_{E,R} > 0$ and discharged when $\Delta E_{E,R} < 0$. A detailed description of the charging and discharging process of the different storage types is given in Technical Release No. 6.

In case of a negative residual load, the energy excess is further reduced by energy consumption of the power-to-heat systems and electrical mobility, which are managed according to the delta, according to Equation (10). A detailed description of the power-to-heat model and the electrical mobility component is given in Technical Release No. 6.

$$\Delta E_{E,R} = \Delta E_{E,R} - P_{PtH} - P_{EMob} \tag{10}$$

with:

$\Delta E_{E,R}$	=	*Electrical energy delta of the region*	*[kW]*
P_{PtH}	=	*Electrical power of the power-to-heat systems*	*[kW]*
P_{EMob}	=	*Electrical energy consumption of the electrical mobility*	*[kW]*

4.2.2 Output

The remaining energy delta corresponds to the energy that has to be exported respectively generated conventionally or imported. If the energy delta exceeds the grid capacities for transportation into other regions in times of energy excesses, potential curtailment losses are assessed neglecting inner regional limitations, losses, and bottlenecks in higher grid levels.

4.3 The management of distributed heat networks

The distributed heat network model allows a flexible set-up the number of connected buildings, and the combination of production and storage types. The distributed heat network fully supplies the heating and hot drinking water demand of buildings, so that locally installed heating systems are not necessary.

The model does not include the simulation of water flows and temperature variations. It is assumed that the network perfectly dimensioned, which means the maximum demand can always be supplied by the grid. The losses in the distribution are modelled independently from temperature variations, energy demand, or the connections.

4.3.1 General equations

The energy consumption is calculated as the hourly energy demand of the buildings specified in the ConsumptionUnit Input file. The losses in the distributed heat network are by a constant loss rate factor shown in Equation (11).

$$C_{NWN} = \left(\sum C_{D,NWN} + \sum C_{ITC,NWN}\right) \cdot \eta_{NWN} \tag{11}$$

with:

C_{NWN}	=	*Energy consumption of the heat network*	*[kW]*
$C_{D,NWN}$	=	*Energy consumption of the residential buildings coupled to the heat network*	*[kW]*
$C_{ITC,NWN}$	=	*Energy consumption of the ITC buildings coupled to the heat network*	*[kW]*
η_{NWN}	=	*Loss rate*	*[-]*

The production is calculated from the production plants specified in the Production Unit. The following types of production plants are considered:

Table 4-4: Description of the production types that can supply the distributed heat networks

Code	Type of production plant	Operation mode	Component
BHS	**Wood-fired heating plant**	**Driven by demand**	**Bioenergy**
BHS	**Wood-gasifier**	**Batch-mode**	**Bioenergy**
BGS	**Biogas plant**	**Base load supply**	**Bioenergy**
SOH	**Ground-mounted solar thermal plant**	**Independently from demand**	**Solar energy**
GPL	**Gas-fired heating system**	**Driven by demand**	**Bioenergy**

The order of the production systems defines the order to supply the energy demand. Due to this, production type with the cheapest costs or in baseload operation mode should be placed first, followed by intermediate systems. The thermal energy plants for peak-load supply as gas-fired heating systems should be placed at the last position. Solar thermal plants are operated independently from the demand in the distributed heating system. Wood-gasifiers are driven in batch-mode and activated as soon as the remaining demand in the previous hour is greater than the minimum power. Wood-fired biomass heating plants and gas-fired plants are managed by the demand of the distributed heat network. The consumption of the previous hour determines the heat production by the wood-fired heating plant and the gas-fired heating system.

The storage flows are calculated similar to the production in the order specified in the StorageUnit with the exception of Power to Heat systems. These systems are considered as the first plant covering the heat demand, if energy excesses are available. The delta is calculated as the difference between consumption and thermal energy production as shown in Equation (12). This delta determines the flows from and to the buffer storages and seasonal heat storages.

$$\Delta E_{Prod,NWN} = C_{NWN} - P_{PtH} - P_{SOH} - P_{BHS} - P_{GPL} - P_{BUF} - P_{SEA} \tag{12}$$

with:

$\Delta E_{Prod,NWN}$	=	*Energy consumption of the heat network*	*[kW]*
P_{PtH}	=	*Power of the power-to-heat system*	*[kW]*
P_{SOH}	=	*Power flow of the solar thermal plant*	*[kW]*
P_{BHS}	=	*Thermal power of the biomass heating system*	*[kW]*
P_{GPL}	=	*Power of the gas plant*	*[kW]*
P_{BUF}	=	*Power of the buffer storage tank*	*[kW]*
P_{SEA}	=	*Power of the seasonal heat storage*	*[kW]*

If the production and storage plants are optimally dimensioned to the consumption profile of the distributed heat network, the energy delta is always reduced to zero.

The following types of storages are considered:

Table 4-5: Description of the storage types that can be integrated into the distributed heat networks

Code	Type of production plant	Operation mode	Component
PTH	**Power-to-Heat system**	**Determined by energy excesses in the region**	**Energy storage**
BUF	**Buffer storage tank**	**Driven by hourly delta in the distributed heat network**	**Energy storage**
SEA	**Seasonal heat storage**	**Driven by hourly delta in the distributed heat network**	**Energy storage**

4.3.2 Input data and format

The setup file for the management of the distributed heat networks contains the following sections:

- [General]:

Table 4-6: Description of the input-file for the Energy Management, Section General

Input Parameters	Description	Unit	Data format
NWNName	Name of the Distributed Heat network	[-]	character
NWNClose	Year of shutdown of the distributed heat network, 1 – if not closed	[-]	integer
NWNID	ID-Number of the Distributed Heat network	[-]	integer
NWNProxel	Pixel of the distributed heat network management	[-]	integer

- [LHN_Model]:

Table 4-7: Description of the input-file for the Energy Management, Section LHN_Model

Input Parameters	Description	Unit	Data format
NWNActive	Status of the distributed heat network	[-]	integer
NWNStartyear, NWN-StartMonth, NWN-StartDay	Start time of the distributed heat network	[-]	integer
NWNLosses	Hourly losses of the network infrastructure	[-]	character

- [ConsumptionUnits]: contains the path of the txt-File with the consumption unit described below

- [ProductionUnits]:

Table 4-8: Description of the input-file for the Energy Management, Section ProductionUnits

Input Parameters	Description	Unit	Data format
No Plants	Number of coupled plants that produce heat energy	[-]	integer
Prod_Type	Production type of the coupled plant	[-]	character
Prod_ID	ID-Number of the coupled plant	[-]	Integer
Prod_Name	Name of the coupled plant	[-]	Character
Prod_Pixel	Pixel number of the coupled plant	[-]	integer

- [StorageUnits]:

Table 4-9: Description of the input-file for the Energy Management, Section StorageUnits

Input Parameters	Description	Unit	Data format
No Plants	Number of coupled plants that store heat energy	[-]	integer
Store_Type	Production type of the coupled plant	[-]	character
Store _ID	ID-Number of the coupled plant	[-]	Integer
Store _Name	Name of the coupled plant	[-]	Character
Store _Pixel	Pixel number of the coupled plant	[-]	integer

Example setup for the distributed heat network management file for a system in Reichersbeuern:

```
[General]
ObjectType              LHN
ObjectName              Reichersbeuern
OBjectModel             1
ObjectId                101
Output-Proxel           233   702
[end]

[LHN_Model]
Active                  1
Startyear               2032
StartMonat              1
StartTag                1
```

```
Losses                 0.9
[end]

[ConsumptionUnits]
EnIn\Nahwaerme\Pot_Reichersbeuern.txt
[end]

[ProductionUnits]
Anzahl der Anlagen     3
Produktionstyp         SOH
Prod_ID                21503
Name der Anlage        5958_Reichersbeuern
Proxel                 244         664
Produktionstyp         BHS
Prod_ID                69
Name der Anlage        Reichersbeuern
Proxel                 233   702
Produktionstyp         GPL
Prod_ID                90
Name der Anlage        Reichersbeuern
Proxel                 233  703
[end]

[StorageUnits]
Anzahl der Anlagen     1
Produktionstyp         BUF
Prod_ID                30
Name der Anlage        Reichersbeuern
Proxel                 233   702
[end]
```

Figure 4-2: Example of the input file for the distributed heat network management file

The setup file for the consumption unit of the distributed heat networks contain the following sections:

- [General]:

Table 4-10: Description of the input-file for the Consumption Unit, Section General

Input Parameters	Description	Unit	Data format
No_Years	Number of years with increase of the connections to the distributed heat network	[-]	integer

- [PixelZubau]:

Table 4-11: Description of the input-file for the Consumption Unit, Section PixelZubau

Input Parameters	Description	Unit	Data format
Year	Year of extension of the distributed heat network	[-]	Integer

No_Pixel	**Number of pixel affected by the extension**	**[-]**	**integer**
Pixel, No_WG, No_NWG, No_Sons	**Pixel number, number of domestic buildings, ITC building and miscellaneous that are connected to the distributed heat network**	**[-]**	**Integer, integer, integer, integer**

Example setup for the consumption unit of a distributed heat network in Reichersbeuern:

```
[General]
Anzahl der Jahre       1
[end]

[PixelZubau]
Jahr                   2014
Pixel                  10
259     572     3     2     0
257     573     2     0     0
258     573     5     0     0
259     573     2     1     0
260     573     1     2     0
261     573     1     2     0
254     574     1     0     0
258     574     4     1     0
259     574     3     0     0
253     575     1     0     0
[end]
```

Figure 4-3: Example of the input file for the consumption unit of a distributed heat network

4.3.3 Pre-processing

The data is taken from literature values like DÖTSCH, et al. (1998). The production and storage systems are restricted to the presented types; their pixel and ID numbers must strictly correspond to the information given in the belonging input files. The buildings connected to the heat networks have to be read in in the input files of the energy consumption component.

The pixel of the management can be determined by overlaying the GIS-Layer with the mask of the model region. The pixel does not necessarily have to represent the geographical location in the grid. However, no further distributed heat networks or storages for thermal energy can be placed on the selected pixel.

4.3.4 Output

The output includes the hourly demand covered by the system and the delta in the network, which cannot be covered by the distributed heating system in case of too low sizing the production plants.

5 Implementation within the Energy Model

The energy management component drives the storage component since the charging and discharging processes are determined from the hourly energy deltas. Depending on the type of storage, different modules are needed.

Table 5-1: Dependencies of the energy storage models on the other energy components

Storage model	Reason	Coupling	Coupled models	Component
Battery model on neighbourhood level or coupled to PV model	Needs PV production and consumption, drives the battery storage operation	Mandatory	Solar energy model, electrical energy demand	Solar energy , Energy consumption, storage component
Buffer storage coupled to solar thermal plant model	Needs thermal energy demand of the building and the solar thermal energy, drives the buffer storage operation	Mandatory	Solar heat model, Thermal energy demand	Solar Energy, Energy consumption, storage component
Buffer storage coupled to surface geothermal plant model	Needs thermal energy demand of the building and the surface geothermal energy, drives the buffer storage operation	Mandatory	Surface geothermal model, Thermal energy demand	Geothermal energy, Energy consumption, storage component
Grid-operated Electrical energy storage models	Needs the regional energy deltas, drives the electrical storage operation	Partly mandatory	Solar energy model, deep geothermal model, biogas model, biomass heating plant, gas plant, hydropower model, wind power model, Electrical energy demand, surface geothermal demand	Solar energy, geothermal energy, bioenergy, hydropower model, Energy consumption, wind power, storage component
Distributed heat network	Needs thermal energy demand, and the thermal energy production, drives the demand-operated systems	Partly mandatory	Biomass/Gas heating plant, Biogas plant, deep geothermal model, solar thermal model, buffer storage model, power-to-heat model, seasonal storage mode, energy consumption	Solar energy, Geothermal energy, Bioenergy, Energy consumption, Storage component

The working flow within the PROMET model and its components for the calculation of the energy paths is shown in Figure 5-1. The hydropower and investment costs component are activated at the beginning of the simulation in the initialization phase of the setup.

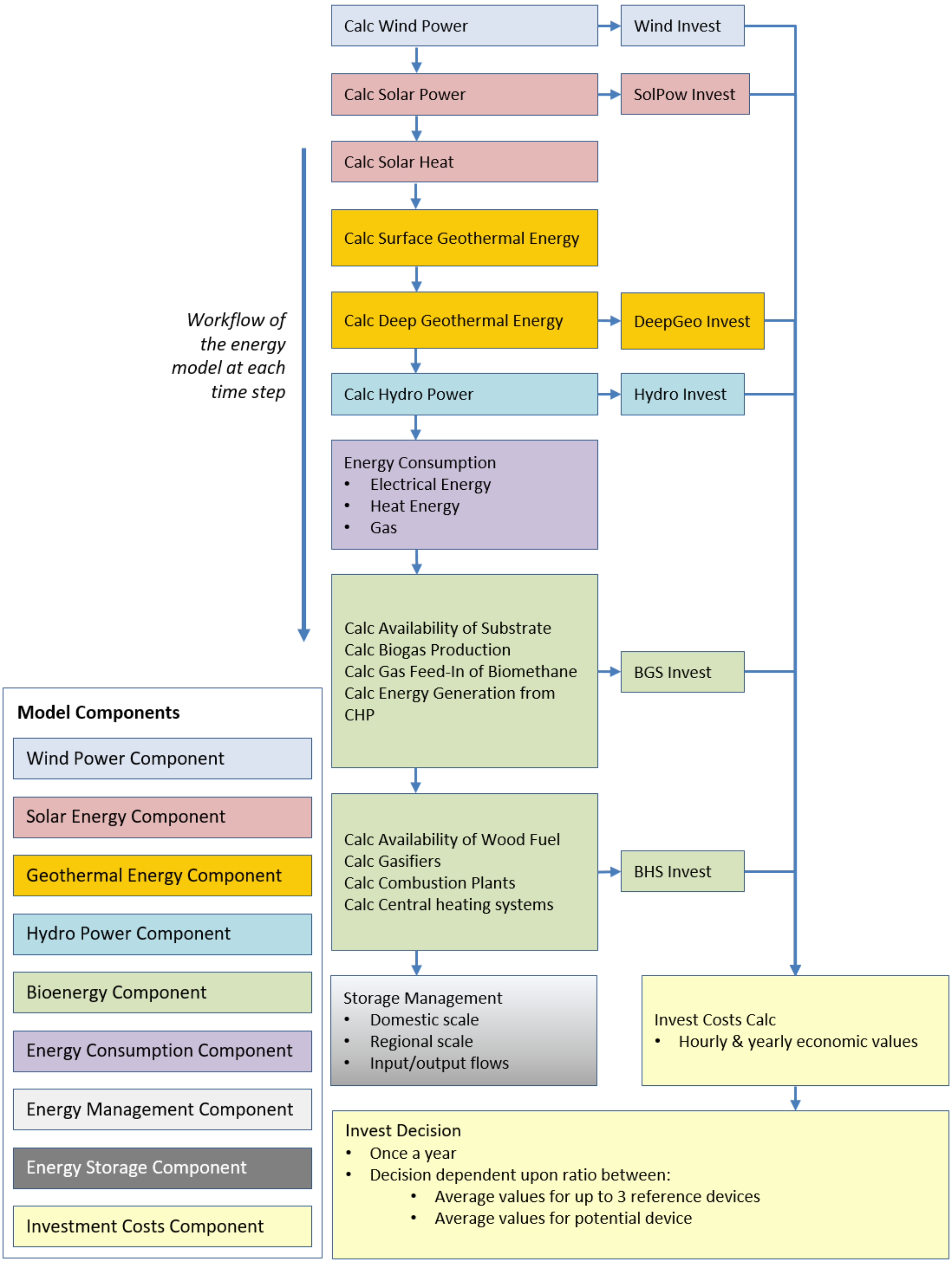

Figure 5-1: Workflow of the Energy model with the regarding components

References

C. DÖTSCH, J. TASCHENBERGER AND I. SCHÖNBERG 1998: (Eds.) Leitfaden Nahwärme. Fraunhofer Institut,Oberhausen.