Technical Release No. 4

June 2018

GEFÖRDERT VOM
Bundesministerium für Bildung und Forschung

FONA Resource Land BMBF

INOLA
INNOVATION FÜR DIE REGION

Technical Release No. 4

– The Bioenergy Component –

Andrea Reimuth and Veronika Locherer

This technical release was issued in the context of the project INOLA (Innovations for a sustainable land and energy management on a regional scale) which is funded by the German Federal Ministry of Education and Research (BMBF) in the period from 2014 to 2019. The author(s) is/are responsible for content and results of this release.

Author(s):

Andrea Reimuth (LMU Munich, Department of Geography, research and teaching unit "Physical Geography and Remote Sensing")

Veronika Locherer (LMU Munich, Department of Geography, research and teaching unit "Physical Geography and Remote Sensing")

Contact:
M.Sc. Andrea Reimuth
Department of Geography
Ludwigs-Maximilians-University Munich
Luisenstr. 37
80333 Munich
E-Mail: a.reimuth@iggf.geo.uni-muenchen.de

All **INOLA-Technical Releases** are available on the project home page www.inola-region.de.

Already published INOLA-Technical releases:

INOLA-Technical Release No. 1:	*INOLA Software Documentation. The Solar Energy Component*
INOLA-Technical Release No. 2:	*INOLA Software Documentation. The Wind Power Component*
INOLA-Technical Release No. 3:	*INOLA Software Documentation. The Hydropower, Geothermal and Environmental Energy Component*
INOLA-Technical Release No. 4:	*INOLA Software Documentation. The Bioenergy Component*
INOLA-Technical Release No. 5:	*INOLA Software Documentation. The Energy Consumption Component*
INOLA-Technical Release No. 6:	*INOLA Software Documentation. The Energy Storage Component*
INOLA-Technical Release No. 7:	*INOLA Software Documentation. The Energy Management Component*
INOLA-Technical Release No. 8:	*INOLA Software Documentation. The Investment Cost Component*

Content

List of Figures

List of Tables

List of Equations

List of Abbreviations

ALH Other deciduous trees with long lifetime

ALN Other deciduous trees with short lifetime

CHP Combined heat and power

1 Introduction

The bioenergy component describes the conversion of biomass to gas, heat and electrical energy. It includes the utilization of grass and maize yields, the production of manure from livestock data and the growth of forests for the supply with wooden fuels. As shown in Table 1-1 six different types of plants are implemented in the component, which are fed by renewable energy sources. The biogas and biomass heating plants in power generation mode are implemented as plants providing base load, whereas biomass heating plants in heating mode, gas plants and the central heating systems are operated continuously to meet the hourly demand in thermal energy from local heat networks or single buildings.

Table 1-1: Implemented models with type of fuel and produced energy

Plant	Fuel	Operation mode	Heat	Electrical Power	Gas
Biogas plant	Grass silage, maize silage, manure, organic waste	Base load	X	X	X
Biomass heating plant	Wood	Base load/Heat operated	X	X	
Gas plant	Gas	Heat operated	X	X	
Central heating – gas fired	Gas	Heat operated	X		
Central heating – wood fired	Wood	Heat operated	X		
Central heating – pellets	Wood	Heat operated	X		

2 The substrate management

Four types of substrate are considered within the bioenergy component: Grass and maize silage, manure, which is gassed within the bio gas plants, and wood as fuel for biomass heating plants and wood-fired plants.

2.1 General equations

2.1.1 Grass and maize

The annual yields of grass and silage maize are calculated within the plant physiology model based on the approach of FARQUHAR, et al. (1980), which is integrated in the PROMET-environment. Further information about the model design, the input data and the outputs of this component are given in HANK (2008), HANK, et al. (2015), MAUSER, et al. (2015).

The availability of substrates for ensilaging is checked once a year for silage maize and three times a year for silage grass from intensive grassland fields at the dates of ensilaging shown in Table 2-1. The yields in tonnes of fresh matter are determined separately for three areas, which are obtained from the harvests for the pixels with land use category 2 and 7.

Table 2-1: Dates for the ensilage and the fermentation end of grassland and maize

Type of substrate	Date of ensilaging	Date of the fermentation end
Grass	30.04.	30.08.
Grass	31.08.	30.12.
Silage maize	30.09.	31.12.
Grass	31.12.	04.29.

To simulate the influence of organic farming practices, the organic yield is decreased by 19.2% compared to conventional practice (PONISIO, et al. 2015). The fraction of ecologic farming is calculated annually from the share at the initial year and the annual increase according to Equation (1).

$$PE_{t+1} = PE_t \cdot (1 + h_{PEa}) \quad (1)$$

with:

PE_t/ PE_{t+1}	=	*Share of ecologic farming at the current year*	*[-]*
h_{Pea}	=	*Annual increase/decrease of ecologic farming*	*[-]*

Equation (2) shows the determination of the total annual yield of maize and grass considering the reductions due to organic farming practices.

$$M_{Y,Mz} = M_{Mz} \cdot (1 - 0.192 \cdot PE_{t+1}) \tag{2}$$

$$M_{Y,G} = M_G \cdot (1 - 0.192 \cdot PE_{t+1})$$

with:

$M_{Y,MZ}$, $M_{Y,G}$	=	*Total yield of maize/grass of the current year*	*[t FM]*
M_{MZ}, M_G	=	*Yield obtained in the plant physiology model*	*[t FM]*

The share of silage maize and grass, which is available for the energy production, is determined according to Equation (3).

$$M_{Mz,A} = M_{Y,Mz} \cdot u_{Mz} \tag{3}$$

$$M_{G,A} = M_{Y,G} \cdot u_G$$

with:

$M_{MZ,A}$	=	*Stock of maize usable for the energy production of the current year*	*[t FM]*
u_{MZ}	=	*Utilization factor for maize*	*[-]*
$M_{G,A}$	=	*Stock of grass usable for the energy production of the current year*	*[t FM]*
u_G	=	*Utilization factor for grass*	*[-]*

It is assumed that the harvest of grass is ensilaged three times per year and the yield of maize each September. The starting dates for ensilaging of the substrates available for the biogas production are listed in Table 2-1.

The total amount of silage maize and silage grass is calculated at the end of the fermentation (dates listed in Table 2-1) using the silage densities of the input file (see chapter 2.3.2) for each district according to Equation (4).

$$M_{totMz,t} = M_{totMz,t-1} + \frac{M_{A,Mz} \cdot \eta_S}{\rho_{MS}} \cdot 1000 \tag{4}$$

$$M_{totG,t} = M_{totG,t-1} + \frac{M_{A,G} \cdot \eta_S}{\rho_G} \cdot 1000$$

with:

M_{totMZ}, M_{totG}	=	*Total stock of silage maize/silage grass*	*[m³]*
t	=	*Day*	*[d]*
ηS	=	*Efficiency of the silaging process of 0.9*	*[-]*
ρMS, ρG	=	*Density of silage maize/silage grass*	*[m3/t FM]*

The stock of grass and maize silage is reduced hourly by the amounts of consumed substrates from the bio gas plants (see chapter 3.1.1) as shown in Equation (5).

$$M_{totMz,t} = M_{totMz,t-1} - M_{consMz,t-1} \quad (5)$$

$$M_{totG,t} = M_{totG,t-1} - M_{consG,t-1}$$

with:

M_{consMZ}, M_{consG}	=	*Amount of consumed silage maize/silage grass*	*[m³]*
t	=	*Hour*	*[h]*

2.1.2 Manure

The total amount of available manure is calculated from the livestock for three areas specified in the input-file described in chapter 4.3. The considered animal types include the following categories:

- dairy
- calves with less than one year
- cattle between one and two years
- cattle with a minimum of two years
- porker
- breeding pigs
- piglets
- sheep
- chickens
- poultry

The current annual livestock is interpolated linearly from the known livestock for the input years for each district at annual resolution (see Equation (6)). For animal categories, which have only one input year, the livestock is kept constant over time.

$$LS(y,a) = LS(y_{t-1},a) + \frac{LS(y_t,a) - LS(y_{t-1},a)}{(y_t - y_{t-1}) \cdot (y - y_{t-1})} \tag{6}$$

with:

LS(y,a)	=	*Live stock of animal type a at year y*	*[pcs.]*
t	=	*Input year*	*[a]*

The amount of manure is calculated daily from the average annual amount of produced manure per animal for each category according to Equation (7).

$$M_{Man,D}(a) = LS(y,a) \cdot \frac{Am(a)}{365} \tag{7}$$

with:

$M_{Man,D}(a)$	=	*Daily amount of manure of the animals of category a at year y*	*[m³]*
Am(a)	=	*Average annual amount of produced manure per animal category*	*[m³/a]*

The amount of produced manure is aggregated as following for the three districts:

- Cattle: dairy, calves with less than one year, cattle between one and two years, cattle with a minimum of two years
- Pigs: Porker, breeding pigs, piglets
- Poultry: chickens, poultry

The availability of the manure for the energy sector is determined by the utilization factor for manure as shown in Equation (8).

$$M_{Cat,D} = \sum_{Cattle} M_{Man,D}(a) \cdot u_M \tag{8}$$

$$M_{Pig,D} = \sum_{Pigs} M_{Man,D}(a) \cdot u_M$$

$$M_{Pou,D} = \sum_{Poultry} M_{Man,D}(a) \cdot u_M$$

with:

$M_{Cat,D}$ / $M_{pig,D}$ / $M_{Pou,D}$	=	*Stock of manure of cattle/pigs/poultry usable for the energy production of the current day d*	*[m³]*
u_M	=	*Utilization factor for manure*	*[-]*

The total amount of manure is calculated for each day as the production sum of all animal categories except sheep:

$$M_{totM,t} = M_{totM,t-1} + M_{Cat,D} + M_{Pig,D} + M_{Pou,D} \tag{9}$$

with:

M_{totM}	=	*Total stock of manure*	*[m³]*
t	=	*Day*	*[d]*

The stock of manure is reduced hourly by the amount of consumed substrate from the bio gas plants (see chapter 3.1.1) as shown in Equation (10).

$$M_{totM,t} = M_{totM,t-1} - M_{consM,t-1} \tag{10}$$

with:

M_{consM}	=	*Amount of consumed manure*	*[m³]*
t	=	*Hour*	*[h]*

2.1.3 Wood

The total amount of available wood is calculated for three areas specified in the input-file described in chapter 2.3.4 at the beginning of each year.

The area covered by forest is determined from pixels with the land use categories coniferous and deciduous trees. The composition of the conifers is partitioned into spruce, fir, douglas, pine and larch. Deciduous trees are classified into oak, beech, ALH (other deciduous trees with high life time) and ALN (other deciduous trees with short life time) by shares, which are constant over time and specified in the input as shown in chapter 2.3.4.. A detailed definition of the used tree categories is given in LWF (2014a).

The stock of available wood is calculated from annual, constant growth rates, which separate between the wood types for deciduous forest and for coniferous forest (see Equation (11) and (12)).

$$M_{Y,Dc} = A_{Dc} \cdot (gr_{oak} \cdot sh_{oak} + gr_{beech} \cdot sh_{beech} + gr_{ALH} \cdot sh_{ALH} + gr_{ALN} \cdot sh_{ALN}) \tag{11}$$

with:

$M_{Y,Dc}$	=	*Total growth of deciduous trees of the current year*	*[m³]*
A_{Dc}	=	*Area that is covered by deciduous forest*	*[hectare]*
gr_{oak} / gr_{beech} / gr_{ALH} / gr_{ALN}	=	*Annual average growth rate of the stock of oak/ beech/ ALH/ ALN*	*[m³/hectare]*
sh_{oak} / sh_{beech} / sh_{ALH} / sh_{ALN}	=	*Average share of oak, beech, ALH and ALN per ha forest*	*[-]*

$$M_{Y,Cf} = A_{Cf} \cdot \left(gr_{spruce} \cdot sh_{spruce} + gr_{fir} \cdot sh_{fir} + gr_{douglas} \cdot sh_{douglas} + gr_{pine} \cdot sh_{pine} + gr_{larch} \cdot sh_{larch}\right) \tag{12}$$

with:

$M_{Y,Cf}$	=	*Total growth of coniferous trees of the current year*	*[m³]*
A_{Cf}	=	*Area that is covered by deciduous forest*	*[hectare]*
gr_{spruce} / gr_{fir} / $gr_{douglas}$ / gr_{pine} /gr_{larch}	=	*Annual average growth rate of the stock of spruce/fir/douglas/pine/larch*	*[m³/hectare]*
sh_{spruce} / sh_{fir} / $sh_{douglas}$ / sh_{pine} / sh_{larch}	=	*Average share of spruce/fir/douglas/pine/larch per ha forest*	*[-]*

The availability of wood for the energy sector is determined by the utilization factors for wood as shown in Equation (13).

$$\begin{aligned} M_{Dc,A} &= M_{Y,Dc} \cdot u_L \cdot u_W \\ M_{Cf,A} &= M_{Y,Cf} \cdot u_L \cdot u_W \end{aligned} \tag{13}$$

with:

$M_{Dc,A}$	=	*Stock of wood usable for the energy production of the current year*	*[m³]*
$M_{Cf,A}$	=	*Stock of wood usable for the energy production of the current year*	*[m³]*

u_L	=	*Logging rate of the available stock of wood*	*[-]*
u_W	=	*Utilization factor for the energy production of wood*	*[-]*

The total amount of available wood is calculated as the sum of the logged, annual wood growth available for the energy sector and the stock of the recent years:

$$M_{totW,t} = M_{totW,t-1} + \left(M_{DC,A} + M_{Cf,A}\right) \cdot u_l \tag{14}$$

with:

M_{totW}	=	*Total stock of wood*	*[m³]*
t	=	*Year*	*[a]*
u_l	=	*Logging rate*	*[-]*

The stock of wood is reduced hourly by the amount of consumed substrate from the central heating systems and the biomass heating plants (see chapters 4.1.1, 0 and 5.1) as shown in Equation (15).

$$M_{totM,t} = M_{totM,t-1} - M_{consM,t-1} \tag{15}$$

with:

M_{consM}	=	*Amount of consumed manure*	*[m³]*
t	=	*Hour*	*[h]*

The mean heat value for deciduous wood and coniferous wood is calculated according to Equation (16).

$$\begin{aligned} hv_{Dc} &= hv_{oak} \cdot sh_{oak} + hv_{beech} \cdot sh_{beech} + hv_{ALH} \cdot sh_{ALH} + hv_{ALN} \cdot sh_{ALN} \\ hv_{Cf} &= hv_{spruce} \cdot sh_{spruce} + hv_{fir} \cdot sh_{fir} + hv_{douglas} \cdot sh_{douglas} + hv_{jaw} \cdot sh_{pine} \\ &\quad + hv_{larch} \cdot sh_{larch} \end{aligned} \tag{16}$$

with:

hv_{Dc}, hv_{Cf}	=	*Average heat value for the stock of deciduous/coniferous wood*	*[kWh/m³]*
hvoak / hvbeech / hvALH / hvALN	=	*Heat value of oak/ beech/ ALH/ ALN*	*[kWh/m3]*

hvSpruce / hvFir / hvDouglas / hvPine / hvLarch	=	*Heat value of spruce/ fir/ douglas/ pine/ larch*	*[kWh/m3]*

The mean heat value for the whole region is finally determined including the shares of the two types of forest as shown in Equation (17).

$$hv_m = \frac{hv_{Dc} \cdot sh_{Dc} + hv_{Cf} \cdot sh_{Cf}}{sh_{Dc} + sh_{Cf}} \tag{17}$$

with:

hv_m	=	*Mean heat value of the stock of wood*	*[kWh/m³]*
sh_{Dc}	=	*Share of deciduous wood*	*[-]*
sh_{Cf}	=	*Share of coniferous wood*	*[-]*

The conversion factors from cubic meters wood to other forms like chippings are taken from LWF (2014b) and shown in Table 2-2.

Table 2-2: Conversion factors for wood fuel types

Type of wood	Conversion factor
Logs (33cm) layered	1.6
Round timber layered	1.4
Logs (33cm) poured	2.1
Chippings	2.5

The production of pellets from the available wood stock is calculated from the demand at each time step as explained in chapter 4.1. The technical characteristics of the pellets according to DIN EN 14961-2 (2011), QUASCHNING (2013) are listed in Table 2-3.

Table 2-3: Technical characteristics of the pellets

Parameter	Value	Unit
Density in poured state	600	[kg/m³]
Heating value	4.93	[kWh/kg]

Losses at production	0.02	[m^3]

2.2 Pre-processing

The input data for the bioenergy management file is taken from literature (BAYLFSTAD 2015, 2017). The pixel containing the information about the stock of substrate types has to be located within the mask. The substrate mixture and the parameter values for the biogas plants are taken from KTBL (2013). The densities are estimated from GALLER (2009) and LWK NIEDERSACHSEN (2006). The heat values for the wood species are taken from LWF (2014b) and the wood densities from HARTMANN, et al. (2013) assuming that the density at 0% water content is similar to 15% water content. The data for the livestock are taken from BAYLFSTAT (2017). The parameters for the stock of wood input file is taken from in LWF (2014a).

2.3 Input data and format

2.3.1 The bioenergy management file

The setup file for the bioenergy management is split into the following sections:

- [BEM_ECO]:

Table 2-4: Description of the input-file for the bioenergy management, Section BEM_ECO

Input Parameters	Description	Unit	Data format
RefYear	Reference year for the fraction of ecologic production	[-]	integer
EcoProd	Percentage of the ecologically cultivated land of the agricultural area for three areas	[-]	real, real, real
EcoRate	Annual growth rates of ecologically cultivated areas for three areas	[-]	real, real, real

- [BEM_SBT]:

Table 2-5: Description of the input-file for the bioenergy management, Section BEM_SBT

Input Parameters	Description	Unit	Data format
DegUtilMaize	Degree of utilization of silage maize for the biogas production for three areas	[-]	real
DegUtilGrass	Degree of utilization of silage grass for the biogas production for three areas	[-]	real

DegUtilManure	**Degree of utilization of manure for the biogas production for three areas**	**[-]**	**real**
DegUtilWood	**Degree of utilization of the logged wood for the energy production**	**[-]**	**real**
LogRate	**Logging rate of the annual growth of wood for three areas**	**[-]**	**real**

- [BEM_BGS]:

Table 2-6: Description of the input-file for the bioenergy management, Section BEM_BGS

Input Parameters	**Description**	**Unit**	**Data format**
PercMaize	**Percentage of maize silage of the substrate input for biogas plants**	**[-]**	**real**
PercGrass	**Percentage of grass silage of the substrate input for biogas plants**	**[-]**	**real**
PercManure	**Percentage of manure of the substrate input for biogas plants**	**[-]**	**real**

- [BEM_PROXEL]:

Table 2-7: Description of the input-file for the bioenergy management, Section BEM_PROXEL

Input Parameters	**Description**	**Unit**	**Data format**
DeciduousProxel1	**Pixel number displaying the stock of utilizable deciduous trees in dm^3 for area 1**	**[-]**	**integer, integer**
ConiferousProxel1	**Pixel number displaying the stock of utilizable conifers in dm^3 for area 1**	**[-]**	**integer, integer**
WoodProxel1	**Pixel number displaying the stock of total utilizable wood in dm^3 for area 1**	**[-]**	**integer, integer**
MaizeSilageProxel1	**Pixel number displaying the stock of utilizable maize silage in m^3 for area 1**	**[-]**	**integer, integer**
GrassSilageProxel1	**Pixel number displaying the stock of utilizable grass silage in m^3 for area 1**	**[-]**	**integer, integer**
CattleManureProxel1	**Pixel number displaying the stock of utilizable cattle manure in m^3 for area 1**	**[-]**	**integer, integer**
PigManureProxel1	**Pixel number displaying the stock of utilizable pig manure in m^3 for area 1**	**[-]**	**integer, integer**
Poultry-ManureProxel1	**Pixel number displaying the stock of utilizable poultry manure in m^3 for area 1**	**[-]**	**integer, integer**
ManureTotProxel1	**Pixel number displaying the stock of total utilizable manure in m^3 for**	**[-]**	**integer, integer**

	area 1		
...	**Pixel numbers for area 2 and 3**		

Example setup for the bioenergy management input file:

```
[BEM_ECO]
RefYear                 2016
EcoProd                 0.20   0.31   0.20
EcoRate                 0.01   0.02   0.01
[end]

[BEM_SBT]
DegUtilMaize            1.00   1.00   1.00
DegUtilGrass            1.00   1.00   1.00
DegUtilManure           1.00   1.00   1.00
DegUtilWood             1.00   1.00   1.00
[end]

[BEM_BGS]
PercMaize               0.6
PercGrass               0.1
PercManure              0.3
[end]

[BEM_Proxel]
DeciduousProxel1        121   502
ConiferousProxel1       121   503
WoodProxel1             121   504
MaizeSilageProxel1      121   505
GrassSilageProxel1      121   506
CattleManureProxel1     121   507
PigManureProxel1        121   508
PoultryManureProxel1    121   509
ManureTotProxel1        121   510
...
[end]
```

Figure 2-1: Example of the input file for the energy management

2.3.2 The substrate parametrization file

The setup file for the substrate parametrization is split into the following sections:

- [General]:

Table 2-8: Description of the input-file for the substrate parametrization, Section General

Input Parameters	Description	Unit	Data format
SubName	**Name of the substrate type**	**[-]**	**character**
SubID	**ID-number of the substrate type**	**[-]**	**integer**

- [SubstrateParams]:

Table 2-9: Description of the input-file for the substrate parametrization, Section SubstrateParams

Input Parameters	Description	Unit	Data format
DryMass	Dry mass of the substrate	[TM/FM]	real
OrgDryMass	Fraction of organic dry mass	[oTM/TM]	real
GasYield	Amount of biogas yield	[l/kg oTM]	real
MethCont	Methane content of biogas	[-]	real
FermRes	Share of fermentation residues of the substrate	[-]	real
Dens	Density of the substrate	[kg FM/m³]	real

- [WoodHVParams]:

Table 2-10: Description of the input-file for the substrate parametrization, Section WoodHVParams

Input Parameters	Description	Unit	Data format
HVOak	Heat value of oak with 15% water content	[kWh/m³]	real
HVBeech	Heat value of beech with 15% water content	[kWh/m³]	real
HVALH	Heat value of other deciduous trees with high life time with 15% water content	[kWh/m³]	real
HVALN	Heat value of other deciduous trees with short life time with 15% water content	[kWh/m³]	real
HVSpruce	Heat value of spruce with 15% water content	[kWh/m³]	real
HVFir	Heat value of fir with 15% water content	[kWh/m³]	real
HVDouglas	Heat value of douglas fir with 15% water content	[kWh/m³]	real
HVPine	Heat value of pine with 15% water content	[kWh/m³]	real
HVLarch	Heat value of larch with 15% water content	[kWh/m³]	real

- [WoodParams]:

Table 2-11: Description of the input-file for the substrate parametrization, Section WoodParams

Input Parameters	Description	Unit	Data format
DensOak	Gross density of oak with 15% water content	[kWh/m³]	real
DensBeech	Gross density of beech with 15% water content	[kWh/m³]	real
DensALH	Gross density of other deciduous trees with high life time with 15% water content	[kWh/m³]	real
DensALN	Gross density of other deciduous trees with low life time with 15% water content	[kWh/m³]	real
DensSpruce	Gross density of spruce with 15% water content	[kWh/m³]	real
DensFir	Gross density of fir with 15% water content	[kWh/m³]	real
DensDouglas	Gross density of douglas fir with 15% water content	[kWh/m³]	real
DensPine	Gross density of pine with 15% water content	[kWh/m³]	real
DensLarch	Gross density of larch with 15% water content	[kWh/m³]	real

Example setup for the substrate parametrization input file:

```
[General]
ObjectType              substrat
SubName                 CattleManure
SubID                   1
[end]

[SubstrateParams]
DryMass                 0.10
OrgDryMass              0.80
GasYield                380
MethCont                0.55
FermRes                 0.98
Dens                    1000
[end]


[WoodHVParams]
HVOak                   2788
HVBeech                 2724
HVALH                   2724
HVALN                   1723
HVSpruce                1926
HVFir                   1926
HVDouglas               1926
HVPine                  2190
```

```
HVLarch                1926
[end]

[WoodParams]
DensOak                0.67
DensBeech              0.75
DensALH                0.63
DensALN                0.52
DensSpruce             0.43
DensFir                0.41
DensDouglas            0.47
DensPine               0.49
DensLarch              0.55
[end]
```

Figure 2-2: Example of the input file for the substrate parametrization

2.3.3 The livestock input file

The setup file for the livestock is split into the following sections:

- [dairy] / [calves_<1y] / [cattle_1_2y] / [cattle_>2y] / [porker] / [breeding_pig] / [piglets] / [sheep] / [chickens] / [poultry]:

Table 2-12: Description of the input-file for livestock, Section Dairy…

Input Parameters	Description	Unit	Data format
NoRefYears	Amount of reference years	[-]	integer
RefYear, LvSt1, LvSt2, LvSt3	Reference year with livestock for three areas	[-, -, -, -]	integer, integer, integer, integer

- [manure]:

Table 2-13: Description of the input-file for the substrate parametrization, Section Manure

Input Parameters	Description	Unit	Data format
ManDairy	Amount of manure of dairy per animal and year	[m³/a]	real
ManCalves_<1y	Amount of manure of calves less than 1 year per animal and year	[m³/a]	real
ManCattle_1_2y	Amount of manure of cattle between 1 and 2 years per animal and year	[m³/a]	real
ManCattle_>2y	Amount of manure of cattle more than 2 years per animal and year	[m³/a]	real
ManPorker	Amount of manure of porkers per animal and year	[m³/a]	real

ManBreeding_pig	**Amount of manure of breeding pigs per animal and year**	**[m³/a]**	**real**
ManPiglets	**Amount of manure of piglets per animal and year**	**[m³/a]**	**real**
ManSheep	**Amount of manure of sheep per animal and year**	**[t/a]**	**real**
ManChicken	**Amount of manure of chicken per 1000 animals and year**	**[t/a]**	**real**
ManPoultry	**Amount of manure of poultry per 1000 animals and year**	**[t/a]**	**real**

Example setup for the livestock input file:

```
[dairy]
NoRefYears             6
2010          20095     18021     37088
2016          18480     16819     34065
2020          18436     16510     33690
2030          17943     15764     32113
2040          17451     15018     30537
2050          16958     14272     28960
[end]

[calves_1y]
...

[manure]
ManDairy               20.00
ManCalves_<1y          6.12
ManCattle_1_2y         10.90
ManCattle_>2y          14.46
ManPorker              3.60
ManBreeding_pig        5.00
ManPiglets             1.05
ManSheep               1.65
ManChicken             1.93
ManPoultry             10.13
[end]
```

Figure 2-3: Example of the input file for livestock

2.3.4 The stock of wood input file

The setup file for the stock of wood is split into the following sections:

- [deciduous_total]:

Table 2-14: Description of the input-file for the stock of wood, section deciduous_total

Input Parameters	Description	Unit	Data format

NoTreeType	Amount of species of deciduous trees	[-]	integer
TreeType, WSt1, WSt2, WSt3	Tree species with stock for three areas	[-, m^3, m^3, m^3]	integer, real, real, real

- [coniferous_total]:

Table 2-15: Description of the input-file for the stock of wood, section coniferous_total

Input Parameters	Description	Unit	Data format
NoTreeType	Amount of species of coniferous trees	[-]	integer
TreeType, WSt1, WSt2, WSt3	Tree species with stock for three areas	[-]	integer, real, real, real

- [forest_growth_m3]:

Table 2-16: Description of the input-file for the stock of wood, Section forest_growth_m3

Input Parameters	Description	Unit	Data format
ForGrowthOak	Annual average growth of oak per ha forest area	[m^3/ha]	real
ForGrowthBeech	Annual average growth of beech per ha forest area	[m^3/ha]	real
ForGrowthALH	Annual average growth of other deciduous trees with high life time per ha forest area	[m^3/ha]	real
ForGrowthALN	Annual average growth of other deciduous trees with low life time per ha forest area	[m^3/ha]	real
ForGrowthSpruce	Annual average growth of spruce per ha forest area	[m^3/ha]	real
ForGrowthFir	Annual average growth of fir per ha forest area	[m^3/ha]	real
ForGrowthDouglas	Annual average growth of douglas per ha forest area	[m^3/ha]	real
ForGrowthPine	Annual average growth of pine per ha forest area	[m^3/ha]	real
ForGrowthLarch	Annual average growth of larch per ha forest area	[m^3/ha]	real

- [wood_share]:

Table 2-17: Description of the input-file for the stock of wood, Section wood_share

Input Parameters	Description	Unit	Data format
ShareOak	Share of the area with oak trees in the total area with deciduous trees	[-]	real
ShareBeech	Share of the area with beech trees in the total area with deciduous trees	[-]	real
ShareALH	Share of the area with other deciduous trees with high life time in the total area with deciduous trees	[-]	real
ShareALN	Share of the area with other deciduous trees with low life in the to-tal area with deciduous trees	[-]	real
ShareSpruce	Share of the area with spruce in the total area with coniferous trees	[-]	real
ShareFir	Share of the area with fir in the total area with coniferous trees	[-]	real
ShareDouglas	Share of the area with douglas in the total area with coniferous trees	[-]	real
SharePine	Share of the area with pine in the total area with coniferous trees	[-]	real
ShareLarch	Share of the area with larch in the total area with coniferous trees	[-]	real

Example setup for the stock of wood input file:

```
[deciduous_total]
NoTreeType          4
Oak                 67960.60      45307.06      30891.18
Beech               4469021.37    2979347.58    2031373.35
ALH                 1728853.97    1152569.31    785842.71
ALN                 753825.46     502550.30     342647.93
[end]

[coniferous_total]
NoTreeType          5
Spruce              18270476.02   12180317.34    8304761.83
Fir                 2538306.56    1692204.37     1153775.71
Douglas             110766.31     73844.21       50348.32
Jaw                 338995.33     225996.89      154088.79
Larch               72017.86      48011.90       32735.39
[end]

[forest_growth_m3]
ForGrowthOak        8.48
ForGrowthBeech      8.36
ForGrowthALH        5.37
ForGrowthALN        7.19
ForGrowthSpruce     11.52
```

```
ForGrowthFir           14.37
ForGrowthDouglas       31.22
ForGrowthPine          2.11
ForGrowthLarch         3.04
[end]

[wood_share]
ShareOak               0.7
ShareaBeech            49.6
ShareALH               33.8
ShareALN               15.9
ShareSpruce            85.6
ShareFir               8.7
ShareDouglas           0.2
SharePine              5.0
ShareLarch             0.4
[end]
```

Figure 2-4: Example of the input file for the stock of wood

2.4 Output

The output includes the amount of consumed gas, wood, maize, grass and manure substrates at hourly resolution for three districts.

3 The biogas plant model

The biogas plants are implemented as energy producers providing base load electrical and heat power.

3.1 General equations

3.1.1 Biogas production

Depending on the type of used substrates, two different biogas models are implemented:

For the biogas production from organic waste like leftover food, the amount of hourly produced biogas is read in from the input file (see chapter 0).

The use of silage maize, silage grass and manure is the standard input into the bio gas plants implemented in this component. The biogas model for this substrate mixture follows the approach of an idealised, continuously stirred tank reactor with constant substrate consumption. The amount of fed-in substrate is calculated by Equation (18).

$$Q_t = \frac{V_{Ferm} \cdot L_{df}}{R_T \cdot 24} \tag{18}$$

with:

Q_t	=	*Amount of the hourly substrate input*	*[m³/h]*
V_{Ferm}	=	*Fermenter volume*	*[m³]*
R_T	=	*Average retention time*	*[d]*
L_{df}	=	*Level of filling of 0.92*	*[-]*

The quantities of the selected substrate types are calculated according to Equation (19) from the substrate shares defined in the BEM-file (see Chapter 2.3.1). If grass silage is not available, it is replaced by manure. The biogas plant ceases the production when it runs out of any of its fed-in substrate types.

$$Q_{Man} = Q_t \cdot P_{Man} \tag{19}$$

$$Q_{Gs} = Q_t \cdot P_{Gs}$$

$$Q_{Ms} = Q_t \cdot P_{Ms}$$

with:

Q_{Man} /Q_{Gs} Q_{Ms}	=	*Amount of the hourly substrate input of manure, grass silage and maize silage*	*[m³/h]*

P_{Gs} /P_{Ms} /P_{Man}	=	*Shares of grass silage, maize silage and manure*	[-]

The hourly yield of biogas is calculated according to Equation (20). The parameters for manure are further classified according to the different characteristics of slurry from cattle, pigs and poultry.

$$Q_{BG} = \frac{Q_{Man} \cdot G_{Man} + Q_{Gs} \cdot TM_{Gs} \cdot oTM_{Gs} \cdot E_{Gs_{oTM}} + Q_{Ms} \cdot TM_{Ms} \cdot oTM_{Ms} \cdot E_{Ms_{oTM}}}{1000} \tag{20}$$

$$G_{Man} = TM_{Cat} \cdot \rho_{Cat} \cdot oTM_{Cat} \cdot E_{Cat_{oTM}} \cdot P_{Cat} + TM_{Pig} \cdot \rho_{Pig} \cdot oTM_{Pig} \cdot E_{Pig_{oTM}} \cdot P_{Pig} + TM_{Pou} \cdot \rho_{Pou} \cdot oTM_{Pou} \cdot E_{Pou_{oTM}} \cdot P_{Pou}$$

with:

Q_{BG}	=	*Amount of produced Biogas*	[m^3]
G_{Man}	=	*Parameter for mixed manure*	[l/kg]
ρ_{Cat} / ρ_{Pig} / ρ_{Pou}	=	*Density of cattle manure/ pig manure/ poultry manure fresh matter*	[kgFM/m^3]
TM_{GS} /TM_{MS} /TM_{Cat} /TM_{pig} /TM_{Pou}	=	*Dry matter of grass silage/maize silage/cattle manure/pig manure/ poultry manure*	[TM/FM]
oTM_{GS} /oTM_{MS} /oTM_{Cat} /oTM_{pig} /oTM_{Pou}	=	*Organic dry matter of silage/maize silage/cattle manure/pig manure/ poultry manure*	[TM/oTM]
$E_{GS_{oTM}}$ /$E_{MS_{oTM}}$ /$E_{Cat_{oTM}}$ /$E_{Pou_{oTM}}$ /$E_{Pig_{oTM}}$	=	*Biogas yield of grass silage/maize silage/cattle manure/pig manure/ poultry manure*	[l/kg_{oTM}]
P_{Cat} /P_{Pig} /P_{Pou}	=	*Percentage of the manure from cattle, pig and poultry*	[-]

The methane content of biogas is calculated according to Equation (21).

$$BG_{CH4} = Q_{Man} \cdot GM_{Man} + Q_{Gs} \cdot TM_{Gs} \cdot oTM_{Gs} \cdot E_{Gs_{oTM}} \cdot C_{Gs_{CH4}} + Q_{Ms} \cdot TM_{Ms} \cdot oTM_{Ms} \cdot E_{Ms_{oTM}} \cdot C_{Ms_{CH4}} \tag{21}$$

$$G_{Man} = TM_{Cat} \cdot \rho_{Cat} \cdot oTM_{Cat} \cdot E_{Cat_{oTM}} \cdot P_{Cat} \cdot C_{Cat_{CH4}} + TM_{Pig} \cdot \rho_{Pig} \cdot oTM_{Pig} \cdot E_{Pig_{oTM}} \cdot P_{Pig} \cdot C_{Pig_{CH4}} + TM_{Pou} \cdot \rho_{Pou} \cdot oTM_{Pou} \cdot E_{Pou_{oTM}} \cdot P_{Pou} \cdot C_{Pou_{CH4}}$$

with:

BG_{CH4}	=	*Amount of produced methane*	[m^3]
$C_{GS_{CH4}}$ /$C_{MS_{CH4}}$ /$C_{Cat_{CH4}}$ /$C_{Pou_{CH4}}$ /$C_{Pig_{CH4}}$	=	*Fraction of CH_4 in biogas of grass silage/maize silage/cattle manure/pig manure/ poultry manure*	[-]

Equation (22) shows the determination of the annually accumulated fermentation residues from the hourly substrate flows.

$$GR_{a,t} = GR_{a,t-1} + Q_{Ms,t} \cdot FF_{Ms} + Q_{Gs,t} \cdot FF_{Gs} + Q_{Man,t} \cdot \left(P_{Cat} \cdot FF_{Cat} + P_{Pig} \cdot FF_{Pig} + P_{Pou} \cdot FF_{Pou}\right) \tag{22}$$

with:

GR	=	*Fermentation residues*	*[m³]*
t	=	*Hour*	*[h]*
FF_{Ms} / FF_{Gs} / FF_{Cat} / FF_{Pig} / FF_{Pou}	=	*Fraction of remaining liquids of grass silage/maize silage/cattle manure/pig manure/ poultry manure*	*[-]*

After a maximum of 8000 h of continuous operation, the biogas plants are turned off for 31.67 days due to cleaning and maintenance.

3.1.2 Biogas utilization

The type of the biogas plant defines the further processing of the produced biogas:

For plants feeding into the gas grid the amount of bio-methane is calculated according to Equation (23). The efficiency parameter includes the energy needed to adapt to the grid pressure, the purification and adjustment of the calorific value.

$$GF_{CH4} = BG_{CH4} \cdot \eta_{GFI} \cdot hv_{Ch4} \tag{23}$$

with:

GF_{CH4}	=	*Amount of methane gas fed into the grid*	*[kWh]*
η_{GFI}	=	*Losses due to methane slips and adaption to the grid*	*[-]*
hv_{CH4}	=	*heat value of methane of 11.03 kWh/m³*	*[kWh/m³]*

If the biogas is utilized onsite by cogeneration plants, the electrical and thermal energy is calculated according to Equation (24) and Equation (25). The produced energy is limited by the maximum thermal and electrical power of the cogeneration plant.

$$P_{el} = Q_{Ch4} \cdot hv_{Ch4} \cdot \eta_{el} \cdot (1 - L_{BG}) \tag{24}$$

with:

P_{el}	=	*Amount of produced electrical energy*	*[kW]*
η_{el}	=	*Electrical efficiency of the cogeneration plant*	*[-]*
L_{BG}	=	*Production losses*	*[-]*

$$P_{therm} = Q_{Ch4} \cdot hv_{Ch4} \cdot \eta_{therm} \cdot (1 - L_{BG}) \quad (25)$$

with:

P_{therm}	=	*Amount of produced thermal energy*	*[kW]*
η_{therm}	=	*Thermal efficiency of the cogeneration plant*	*[-]*
L_{BG}	=	*Production losses*	*[-]*

3.2 Pre-processing

The data is taken from literature (FNR 2013, KTBL 2013). The pixel of the plants can be determined by overlaying the GIS-Layer with the mask of the model region.

The fermenter volume can be estimated from the plant's nominal power by Equation (26) based on the linearly interpolated results of KTBL (2017) (see Appendix Table A 1 and Figure A 1). The underlying assumption is that a substrate share of 60 % maize silage, 30 % cattle manure and 10 % grass silage is used.

$$V_{Ferm} = 6.5855 \cdot P + 21.037 \quad (26)$$

with:

V_{Ferm}	=	*Fermenter volume*	*[l]*
P	=	*Nominal Power of the Biogas plant*	*[kW]*

3.3 Input data and format

The setup file for the Biogas plants is split into the following sections:

- [General]:

Table 3-1: Description of the input-file for the biogas plant-model, Section General

Input Parameters	Description	Unit	Data format
BGSName	Name of the Biogas plant	[-]	character
BGSID	ID-number of the Biogas plant	[-]	integer
BGSProxel	Pixel of the Biogas plant	[-]	integer

- [BioGasPlant]:

Table 3-2: Description of the input-file for the biogas plant-model, Section BioGasPlant

Input Parameters	Description	Unit	Data format
BGSActive	Status of the biogas plant: 0 – off, 1 – on	[-]	integer
BGSStartYear, BGSStartMonth, BGSStartDay	Start time of the biogas plant	[-]	integer
BGSType	Biogas utilization: 1 – cogeneration plant, 2 – feed-into the gas grid	[-]	integer
FermVol/OWGas	Volume of the fermenter for BGS-model 1, Hourly amount of bio methane for BGS-model 2	[m³]	real
BGSModel	Substrate input: 1 – as defined in BEM-file, 2 – organic waste	[-]	integer
ConvLoss	Biogas/Methane losses at the gas production	[-]	real
RetTime	Average retention time of the substrate	[d]	integer
Nu_el	Electrical efficiency of the cogeneration plant	[-]	real
Nu_therm	Thermal efficiency of the cogeneration plant	[-]	real
Nu_chem	Conversion efficiency of the biomethane facility	[-]	real
P_el	Maximum electrical power of the cogeneration plant	[kW]	real
P_therm	Maximum thermal power of the cogeneration plant	[kW]	real

Example setup for a biogas plant located in Rottenbuch:

```
[General]
ObjectType              biogas
BGSName                 E31177010000000005007779678-00000
BGSID                   1
BGSProxel               297    197
[end]

[BioGasModel]
BGSActive               1
BGSStartYear            2005
BGSStartMonth           09
BGSStartDay             29
BGSType                 1
FermVolume              1054
BGSModel                1
ConvLoss                0.01
RetTime                 38
Nu_el                   0.369
Nu_therm                0.489
Nu_chem                 0.000
P_el                    140
P_therm                 185
[end]
```

Figure 3-1: Example of the input file for the biogas plant model

3.4 Output

The output of the biogas plant model includes the amount of produced electrical and thermal energy of the cogeneration plants as well as the gas output of plants producing biomethane. The biomass conversion used for gas production is shown by the amount of consumed substrates and the fermentation residues.

4 The central heating model

Three types of domestic heating systems are implemented in this component:

- Wood-fired systems with continuous woodchip supply
- Pellet-heating systems that are coupled to buffer storages and solar thermal plants
- Gas-fired heating systems, such as gas fired water heaters

It is assumed that the vessels of the central heating systems are dimensioned sufficiently in performance and size, so that the energy demand is always fully provided at each hour.

4.1 General equations

4.1.1 Wood-fired heating systems

The wood-fired systems are operated with an automatic wood chips feed-in. The amount of wood needed to supply the thermal energy demand of all buildings with wood-fired heating systems is calculated according to Equation (27).

$$D_w = \sum_{i=1}^{n_{whf}} \frac{E_{th}(i)}{\eta_{WH} \cdot hv_m} \tag{27}$$

with:

D_W	=	*Demand in wood*	*[m³]*
E_{th}	=	*Thermal energy demand of the building*	*[kW]*
η_{WH}	=	*Efficiency of wood-fired heating system*	*[-]*
n_{whf}	=	*Total number of wood-fired heating systems*	*[-]*

4.1.2 Pellet-systems

For wood-fired systems coupled to solar thermal plants and buffer storages, the amount of heat energy that is supplied by pellet vessels is calculated in the buffer storage model. It is assumed that the pellet vessels always secure the excess of the minimum demanded energy content of the buffer storages (see Technical Release No. 6 Chapter 6).

Equation (28) shows the calculation of the pellet demand from the difference between the current and the minimum thermal energy content of the buffer tanks. It is assumed that the pellet vessels have a constant efficiency of 92.5% according to HARTMANN, et al. (2013) and that there is a material loss of 2% during the production of pellets.

$$D_W = \sum_{i=1}^{n_{sts}} \frac{\Delta E_{buf}(i)}{(1 - L_P) \cdot \eta_{PlH} \cdot hv_{Pl} \cdot \rho_{Pl}} \tag{28}$$

with:

D_W	=	*Demand in wood*	*[m³]*
ΔE_{buf}	=	*Thermal energy demand of the buffer storage*	*[kW]*
L_P	=	*Losses of the pellet production*	*[-]*
η_{PlH}	=	*Efficiency of the pellet heating system*	*[-]*
n_{STS}	=	*Total number of solar thermal plant systems*	*[-]*
ρ_{Pl}	=	*Density of the pellets*	*[kg/m³]*
hv_{PlH}	=	*Heating value of the pellets*	*[kWh/kg]*

4.1.3 Gas-fired heating systems

Gas fired heating systems are modelled with a similar approach like the wood-fired central heating systems described in chapter 4.1.1. The demand in gas per hour is calculated from the energy demand of the buildings using gas-fired vessels according to Equation (29).

$$D_G = \sum_{i=1}^{n_{ghf}} \frac{E_{th}(i)}{\eta_{GH}} \tag{29}$$

with:

D_G	=	*Demand in gas*	*[kW]*
E_{th}	=	*Thermal energy demand of the building*	*[kW]*
η_{GH}	=	*Efficiency of the gas-fired heating system*	*[-]*
n_{ghf}	=	*Total number of gas-fired heating systems*	*[-]*

4.2 Pre-processing

The parameter data is taken from literature (HARTMANN, et al. 2013, FNR 2017). The pixel of the plant can be determined by overlaying the GIS-Layer with the mask of the model region.

4.3 Input data and format

Input data for the pellet heating systems coupled to solar thermal plants and buffer storages is not necessary, as the required information is already part of the production and storage input files.

The input for spatially distributed wood and gas fired heating systems is stored in raster files in PIC-format with the following layers:

Table 4-1: Description of the input-file for central heating systems in PIC-Format

Input Parameters	Description	Unit	Data format
NWFH	Number of wood-fired heating systems per pixel	[-]	integer
WFHStart	Starting year of wood-fired heating systems per pixel	[-]	integer
NGFH	Number of gas-fired heating systems per pixel	[-]	integer
NGFHStart	Starting year of gas-fired heating systems per pixel	[-]	integer
LK	Allocation number of the administrative district	[-]	integer
GEM	Allocation number of the municipality	[-]	integer

4.4 Output

The output includes the amount of consumed wood in m^3 and gas in kWh per district and the produced heat energy in kWh.

5 The biomass heating plant model

Three operation modes of biomass heating plants are implemented in this component:

- The **wood-fired heating model**, which can be operated in partial load to meet the hourly demand in thermal energy. The energy consumption of the previous hour calculated in the local heat network component is the amount of heat production for the current hour. Further details are described in Technical Release No. 7 Chapter 2.
- The **wood-gasifier model**, which corresponds to a batch system. The vessel is filled and operated at maximum performance until the fuel is completely burned. This type has to be coupled to a buffer tank or local heat network, as the start time of the wood-gasifier is determined externally.
- The **power generation model**, which delivers electric power for base load supply. This model does not have to be coupled to local heat networks mandatory, when the waste heat is not used.

5.1 General equations

The biomass heating plant is activated after reaching the start date specified in the input file. The consumption of wood is aggregated to the level of the administrative districts.

5.1.1 The wood-fired heating model

The wood-fired heating model accepts all types of wooden solid fuels, which are specified for each plant in the variable BHSFuelType of the input file.

According to FNR (2017) it is assumed that the wood-fired heating systems operate in a partial load range of 30%-100% of the rated power. Furthermore, the full supply with solid fuel is always secured at each time step.

The consumption of wood for the wood-fired heating plant is calculated according to Equation (30).

$$C_W(t) = \frac{D_{therm}(t-1)}{\eta_{therm} \cdot hv_m} \quad (30)$$

with:

$C_W(t)$	=	*Consumption of the wooden solid fuel at time step t*	*[m³]*
$D_{therm}(t-1)$	=	*Thermal energy demand of the local heat network from time step t-1*	*[kW]*
η_{fermh}	=	*Thermal efficiency of the wood-fired heating*	*[-]*

The calculation of the electric energy production for cogeneration plants is shown in Equation (31).

$$E_{el} = \frac{D_{therm}(t-1)}{\eta_{therm}} \cdot \eta_{el} \tag{31}$$

with:

E_{el}	=	*Produced electric energy*	*[kW]*
η_{wfh}	=	*Electric efficiency of wood-fired heating*	*[-]*

5.1.2 The wood gasifier model

In the wood gasifier model, the possible fuel types are restricted to round timbers and poured logs with a size of 33 cm. The feeding of the plant is determined in the component of the local heat networks as explained in Technical Release No. 7 chapter 2.

Equation (32) shows the calculation of the feeding of a plant after activation.

$$C_W = \frac{V_{wg}}{f_{conv} \cdot 1000} \tag{32}$$

with:

C_W	=	*Amount of consumed wood fuel*	*[m³]*
V_{wg}	=	*Volume of the wood gasifier vessel*	*[l]*

The combustion period, which can be achieved from the wood filling, is calculated according to Equation (33). It is assumed that the plant is operated at rated thermal and electric power during the operation time.

$$t_{cb} = \frac{C_W \cdot hv_m}{P_{therm}} \cdot \eta_{therm} \tag{33}$$

with:

t_{cb}	=	*Combustion time*	*[h]*
P_{therm}	=	*Rated thermal power of the wood gasifier plant*	*[kW]*
η_{therm}	=	*Thermal efficiency of the wood gasifier plant*	*[-]*

When the remaining combustion time is less than one hour, this information is further processed in the local heat network component, in which the decision of the refuelling is taken.

5.1.3 The power-generation model

The biomass plants that are operated in the mode of base-load supply have a constant consumption of wood as shown in Equation (34).

$$C_W = \frac{P_{el}}{hv_m \cdot \eta_{el}} \tag{34}$$

with:

C_w	=	*Consumption of wood*	*[m³]*
P_{el}	=	*Rated electric power of the biomass plant*	*[kW]*
η_{el}	=	*Electric efficiency of the biomass plant*	*[-]*

After 8000 h of operation, the biomass plants are turned off for 31.67 days due to cleaning and maintenance.

5.2 Pre-processing

The data is taken from literature (FNR 2015, 2017). The pixel numbers of the plants can be determined by overlaying the GIS-Layer with the mask of the model region.

The vessel size of the wood gasifier can be estimated from the performance by Equation (35) based on the linearly interpolated results of the list in FNR (2015) with manufacturer information (see Figure A 2).

$$V_{WG} = 5.3265 \cdot P_{WG} \tag{35}$$

with:

V_{WG}	=	*Vessel volume of the wood gasifier*	*[l]*
P_{WG}	=	*Thermal performance of the wood gasifier*	*[kW]*

5.3 Input data and format

The setup file for the Biomass heating plants is split into the following sections:

- [General]:

Table 5-1: Description of the input-file for the biomass heating plant-model, Section General

Input Parameters	Description	Unit	Data format
BHSName	Name of the biomass heating plant	[-]	character
BHSID	ID-number of the biomass heating plant	[-]	integer
BHSProxel	Pixel	[-]	integer

- [BioMassModel]:

Table 5-2: Description of the input-file for the biomass heating plant-model, Section BioMassPlant

Input Parameters	Description	Unit	Data format
BHSActive	Status of the biomass heating plant: 0 – off, 1 – on	[-]	integer
BhSStartYear, BHSStartMonth, BHSStartDay	Starting time of the biomass heating plant	[-]	integer
BHSFuelType	Type of fuel: 1 – logs (33cm) layered, 2 – round timber, 3 – logs (33cm) poured, 4 – chippings, 5 – pellets	[-]	integer
ComChamVol	Volume of the combustion chamber	[l]	real
BHSModel	Heating model: 1 – wood-fired heating, 2 – wood gasifier, 3 – power generation	[-]	integer
Nu_el	Electrical efficiency of the biomass heating plant	[-]	real
Nu_therm	Thermal efficiency of the biomass heating plant	[-]	real
P_el	Maximum electrical power of the biomass heating plant	[kW]	real
P_therm	Maximum thermal power of the biomass heating plant	[kW]	real

Example setup for a biomass heating plant located in Steingaden:

```
[General]
ObjectType              biomass
```

```
BHSName             Steingaden
BHSID               1
BHSProxel           331     118
[end]

[BioMassModel]
BHSActive           1
BHSStartYear        2005
BHSStartMonth       1
BHSStartDay         1
BHSFuelType         4
ComChamVol          0
BHSModel            1
Nu_el               0.325
Nu_therm            0.895
P_therm             400
P_el                0
[end]
```

Figure 5-1: Example of the input file for the biomass heating plant model

5.4 Output

The output includes the amount of produced heat and electric energy as well as the consumed wood in dm^3 for each plant.

6 The gas plant model

This model component includes gas-fired power plants and combined heat and power plants (CHP).

One operation modes of gas plants is implemented in this component:

The **gas-fired heating model**, which can be operated in partial load to meet the hourly demand in thermal energy. The energy consumption of the previous hour calculated in the local heat network component is the amount of heat production for the current hour. Further details are described in Technical Release No. 7 Chapter 2.

6.1 General equations

The gas plant is activated after reaching the start date specified in the input file.

6.1.1 The gas-fired heating model

The gas-fired heating plant is strictly operated according to the demand in thermal energy of the heat networks. Surplus electrical energy is fed into the grid. The maximum thermal energy, which can be produced, is limited to the thermal power of the plant.

The hourly consumption of gas is calculated according to Equation (30).

$$C_G(t) = \frac{D_{therm}(t-1)}{\eta_{th,G}} \tag{36}$$

with:

C_G (t)	=	*Consumption of gas at time step t*	*[kWh]*
D_{therm} (t-1)	=	*Thermal energy demand of the local heat net-work from time step t-1*	*[kW]*
$\eta_{th,G}$	=	*Thermal efficiency of the gas-fired heating of :::::*	*[-]*

The calculation of the electric energy production for cogeneration plants is shown in Equation (31).

$$E_{el} = \frac{D_{therm}(t-1)}{\eta_{th,G}} \cdot \eta_{el,G} \tag{37}$$

with:

E_{el}	=	*Produced electric energy*	*[kW]*
$\eta_{el,G}$	=	*Electric efficiency of gas-fired heating*	*[-]*

6.2 Pre-processing

The data is taken from literature. The pixel numbers of the plants can be determined by overlaying the GIS-Layer with the mask of the model region.

6.3 Input data and format

The setup file for the gas plants is split into the following sections:

- [General]:

Table 6-1: Description of the input-file for the gas plant-model, Section General

Input Parameters	Description	Unit	Data format
GPLName	Name of the gas plant	[-]	character
GPLID	ID-number of the gas plant	[-]	integer
GPLProxel	Pixel	[-]	integer

- [GasPlantModel]:

Table 6-2: Description of the input-file for the gas plant-model, Section GasPlantModel

Input Parameters	Description	Unit	Data format
GPLActive	Status of the gas plant: 0 – off, 1 – on	[-]	integer
GPLStartYear, GPLStartMonth, GPLStartDay	Starting time of the gas plant	[-]	integer
GPLModel	Gas plant model: 1 – gas-fired heating, 2 – cogeneration, 3 – power generation,	[-]	integer
Nu_el	Electrical efficiency of the gas plant	[-]	real
Nu_therm	Thermal efficiency of the gas plant	[-]	real
P_el	Maximum electrical power of the gas plant	[kW]	real
P_therm	Maximum thermal power of the gas plant	[kW]	real

Example setup for a gas plant for peak supply of a local heat network located in Steingaden:

```
[General]
ObjectType              gas
GPLName                 Steingaden
GPLID                   1
GPLProxel               331     118
[end]

[GasPlantModel]
GPLActive               1
GPLStartYear            2005
GPLStartMonth           1
GPLStartDay             1
GPLModel                1
Nu_el                   0.
Nu_therm                0.
P_therm                 500
P_el                    0
[end]
```

Figure 6-1: Example of the input file for the gas plant model

6.4 Output

The output includes the amount of produced heat and electric energy as well as the consumed gas in kWh for each plant.

7 Implementation within the energy model

The bioenergy component is executed after the energy production and the energy consumption models. Depending on the type of plant, the biomass models are coupled to different storage models with a time delay of one hour or the consumption model as shown inTable 7-1.

Table 7-1: Dependencies of the bio energy models on the other energy components

Bioenergy model	Reason	Coupling	Coupled models	Component
Biogas plant	Provides utilization of waste heat	Non mandatory	Local heat network	Storage management
Central heating model Wood-fired heating	Needs thermal energy demand of the building	Mandatory	Thermal energy demand	Energy consumption
Central heating model Pellet heating	Needs energy to excess minimum energy content of the buffer	Mandatory	Buffer model, solar thermal energy model	Energy storage, energy management, solar thermal energy
Central heating model Gas-fired heating	Needs thermal energy demand of the building	Mandatory	Thermal energy demand	Energy consumption
Biomass heating plant model Wood-fired heating	Needs thermal energy demand of the linked local heat network of the previous hour	Mandatory	Local heat network	Storage management
Biomass heating plant model Wood-gasifier	Needs activation and switch off order of the local heat network	Mandatory	Local heat network	Storage management
Biomass heating plant model Power-generation mode	Provides utilization of waste heat	Non mandatory	Local heat network	Storage management
Gas plant Peak-load mode	Needs thermal energy demand of the linked local heat network of the previous hour	Mandatory	Local heat network	Storage management
Gas plant Power generation mode	Provides utilization of waste heat	Non mandatory	Local heat network	Storage management

References

BayLfStaD 2017: Landwirtschaftliche Betriebe mit ökologischem Landbau 2016 nach jeweiligen ökologischen Flächen und Anbaukulturen Bayern. München:

BayLfStaD 2015: Landwirtschaftszählung - Haupterhebung, allg. Ldw. Fläche (ha): Berichtsjahr: 2010. Bayerisches Landesamt für Statistik und Datenverarbeitung.

BAYLFSTAT 2017: Agrarstrukturerhebung: Landwirtschaftliche Betriebe mit Viehhaltung und Viehbestand am 1. März 2016 nach Tierarten und regionaler Einheit. Available at: www.statistikdaten.bayern.de (17.10.2017: 17.10.2017).

DIN EN 12831-1:2017-09 (Eds.) Energetische Bewertung von Gebäuden - Verfahren zur Berechnung der Norm-Heizlast. (EN 12831-1:2017-09).

DIN EN 14961-2 2011 (Eds.) Feste Biobrennstoffe – Brennstoffspezifikationen und -klassen – Teil 2: Holzpellets für nichtindu-strielle Verwendung(14961-2). Deutsches Institut für Normung e.V. (DIN). Beuth Verlag,Berlin.

FARQUHAR, G. D., VON CAEMMERER, S. AND BERRY, J. A. 1980: A biochemical model of photosynthetic CO2 assimilation in leaves of C3 species. *Planta*, 149(1), 78-90.

FNR 2017: Hackschnitzelheizungen. Fachagentur Nachwachsende Rohstoffe e. V. .

FNR 2013: Leitfaden Biogas. Von der Gewinnung zur Nutzung. Fachagentur Nachwachsende Rohstoffe e. V. , Gülzow-Prüzen.

FNR 2015: Scheitholzvergaser-/Kombikessel. Fachagentur für nachwachsende Rohstoffe (FNR).

GALLER, J. 2009: (Eds.) Wirtschaftsdünger. Anfall, Lagerung, Verwertung, Umwelt. Praxisratgeber von Josef Galler. Landwirtschaftskammer Salzburg,Salzburg.

HANK, T. 2008: A Biophysically Based Coupled Model Approach for the Assessment of Canopy Processes Under Climate Change Conditions. LMU München.

HANK, T., BACH, H. AND MAUSER, W. 2015: Using a Remote Sensing-Supported Hydro-Agroecological Model for Field-Scale Simulation of Heterogeneous Crop Growth and Yield: Application for Wheat in Central Europe. *Remote Sensing*, 7(4), 3934.

HARTMANN, H., REISINGER, K., TUROWSKI, P. AND ROßMANN, P. 2013: Handbuch Bioenergie-Kleinanlagen Gülzow: Fachagentur Nachwachsende Rohstoffe (FNR).

KTBL 2013: Faustzahlen Biogas. Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (KTBL), Darmstadt.

KTBL 2017: Wirtschaftlichkeitsrechner Biogas. Available at: http://daten.ktbl.de/biogas/navigation.do?selectedAction=Startseite#start (22.03.2018: 22.03.2018).

LWF 2014A: Die Ergebnisse der Bundeswaldinventur 2012 für das Bundesland Bayern. Bayerische Landesanstalt für Wald und Forstwirtschaft. Available at: http://www.bundeswaldinventur.bayern.de (08.01.2016: 08.01.2016).

LWF 2014B: (Eds.) Merkblatt 12. Der Energieinhalt von Holz. Bayerische Landesanstalt für Wald und Forstwirtschaft (LWF),Freising.

LWK NIEDERSACHSEN 2006: L. NIEDERSACHSEN (Eds.) Handbuch Futter und Fütterung - Rinder. Landwirtschaftskammer Niedersachsen Futterberatungsdienst Niedersachsen e. V.

MAUSER, W., BACH, H., FRANK, T., HANK, T., KOCH, F., MARKE, T., MUERTH, M., PRASCH, M., STRASSER, U. AND ZABEL, F. 2015: PROMET–Processes of Mass and Energy Transfer. *An*

Integrated Land Surface Processes and Human Impacts Simulator for the Quantitative Exploration of Human-Environment Relations. Part, 1.

PONISIO, L. C., M'GONIGLE, L. K., MACE, K. C., PALOMINO, J., DE VALPINE, P. AND KREMEN, C. 2015: Diversification practices reduce organic to conventional yield gap. *Proc. R. Soc. B*, 282(1799), 20141396.

QUASCHNING, V. 2013: Regenerative Energiesysteme. Technlogie - Berechnung - Simulation. Carl Hanser Verlag, München.

A. Appendix

Table A 1: Fermenter volume and nominal electrical power of biogas plants using on-site combustion with a gas Otto engine and 8000 h of full load hours for different substrate inputs according to KTBL (2017)

No. of input	Substrate [t FM/a]			Nominal power [kW]	Fermenter volume [l]
	Maize silage	Cattle manure	Grass silage		
1st Input	1,500	750	250	93	582
2nd Input	3,000	1,500	500	193	1,164
3rd Input	6,000	3,000	1,000	406	2,795
4th Input	12,000	6,000	2,000	859	5,589

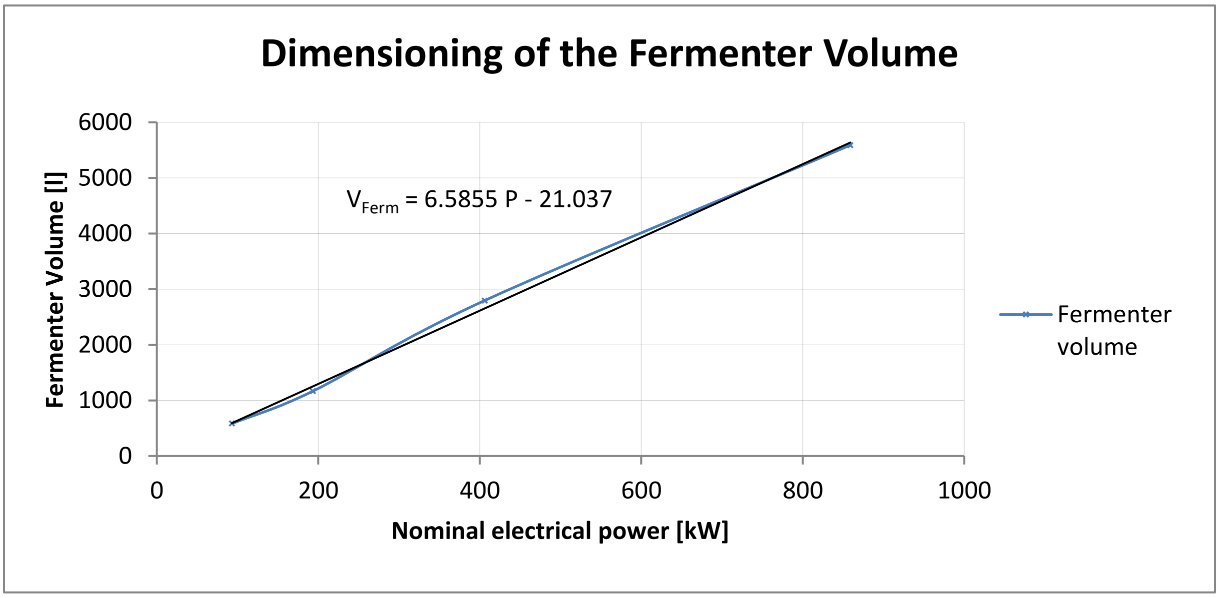

Figure A 1: Determination of the linear parameters from the obtained fermenter volumes and nominal electrical power for the selected substrate input amounts

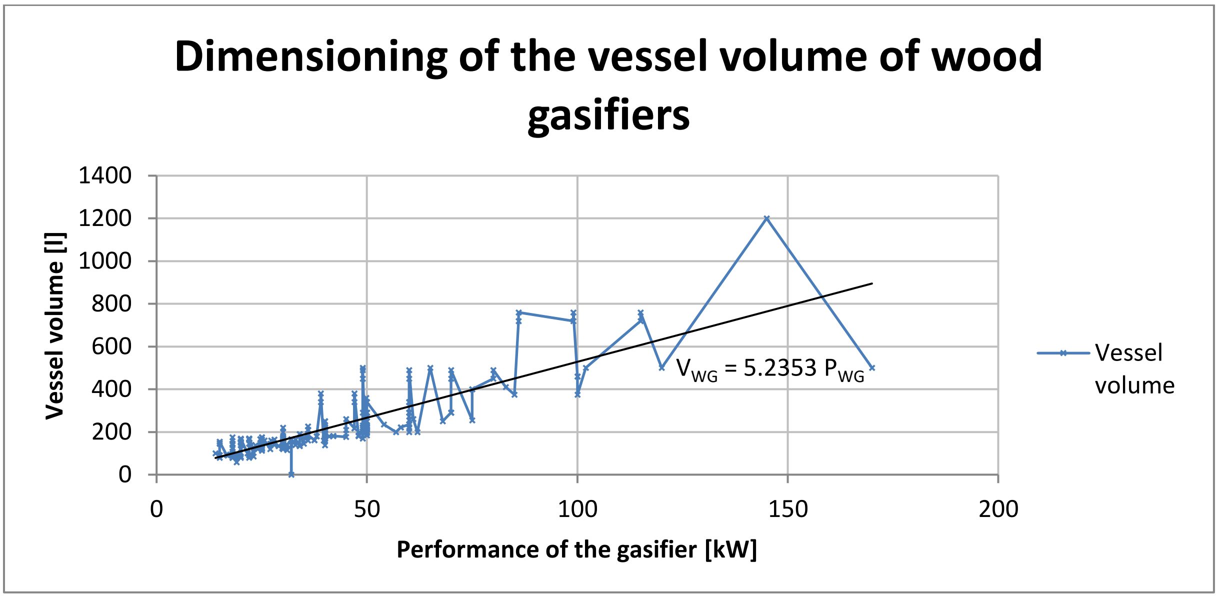

Figure A 2: Determination of the parameters for the obtained vessel volume of the wood gasifiers from the thermal performance according to manufacturer data collected in FNR (2015)