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INOLA Software Documentation

– The Wind Power Component –

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INOLA-Technical Release No. 1:	*INOLA Software Documentation. The Solar Energy Component*
INOLA-Technical Release No. 2:	*INOLA Software Documentation. The Wind Power Component*
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INOLA-Technical Release No. 4:	*INOLA Software Documentation. The Bioenergy 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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1 The Wind Power Component

The Wind Power Component aims to simulate power production via wind turbines. The component consists of five models representing five different types of wind turbines. Within all models, wind speed is calculated for the corresponding height of the turbine and inserted into a polynomial function that was derived individually for each turbine type. The component does include the possibility for dynamic decision-making about the new construction or refurbishment of windpower plants based on economic criteria (see *INOLA-Technical Release No. 8: The Investment Cost Component*).

1.1 General Equations

1.1.1 Wind Speed Module

The wind speed module calculates wind speed at hub height of each turbine and is based on the so called power-law after Hellman as shown in Equation (1) (HAU 2013).

$$v_{hub} = v_1 * \left(\frac{h_{hub}}{h_1}\right)^{\alpha} \tag{1}$$

with:

v_1	=	*Wind speed near surface*	$\left[\frac{m}{s}\right]$
h_1	=	*Height of near-surface wind measurements*	$[m]$
h_{hub}	=	*Hub height of turbine*	$[m]$
α	=	*Hellmann exponent*	$[-]$

The Hellmann exponent is calculated via the following equation:

$$\alpha = \frac{1}{\log \frac{h_{hub}}{z_0}} \tag{2}$$

with:

h_{hub}	=	*Hub height of turbine*	$[m]$
z_0	=	*Roughness length of ground*	$[m]$

Table 1-1: Description of parameters used in the wind speed module with associated variable names

Symbol	Description	Unit	Variable name(s)
v_1	Wind speed near surface	$\left[\frac{m}{s}\right]$	WindSpeed
h_1	Height of wind speed measurements	$[m]$	Height
h_{hub}	Hub height of turbine	$[m]$	HubHeight
α	Hellmann exponent	$[-]$	HELLMAN
z_0	Roughness length of ground	$[m]$	Roughness

1.1.2 Electric Power Production Module

The electric power production module is based on performance curves of the individual turbine types as provided by the manufacturers and consists of five different models. For each of these types a mathematical model was developed to fit the performance curve. Thresholds used for the models were cut-in and cut-out wind speed (at which speed the turbines start or stop to perform) as well as rated output speed (where the turbine reaches its optimum). In the following the five different Wind Models are presented.

1.1.2.1 WindModel1

WindModel1 describes a turbine with a hub height of 10 m and a maximum output of 1.5 kW (LUVTEC GMBH n.d.). The power output is calculated via Equations (3) to (8) which are derived from the corresponding performance curve (Figure 1-1).

$$E_{Wind} = 0 \qquad v_{hub} \in [0; 3.5] \tag{3}$$

$$E_{Wind} = 0.0108 * {v_{hub}}^2 - 0.0385 * v_{hub} + 0.0321 \qquad v_{hub} \in]3.5; 7[\tag{4}$$

$$E_{Wind} = 0.0225 * {v_{hub}}^2 - 0.2115 * v_{hub} + 0.6765 \qquad v_{hub} \in [7; 10[\tag{5}$$

$$E_{Wind} = -0.02 * {v_{hub}}^3 + 0.635 * {v_{hub}}^2 - 6.395 * v_{hub} + 21.26 \qquad v_{hub} \in [10; 13[\,; \; E_{Wind} \in [0; 1.5] \tag{6}$$

$$E_{Wind} = 1.5 \qquad v_{hub} \in [13; 17[\tag{7}$$

$$E_{Wind} = 0 \qquad v_{hub} \in [17; \infty[\tag{8}$$

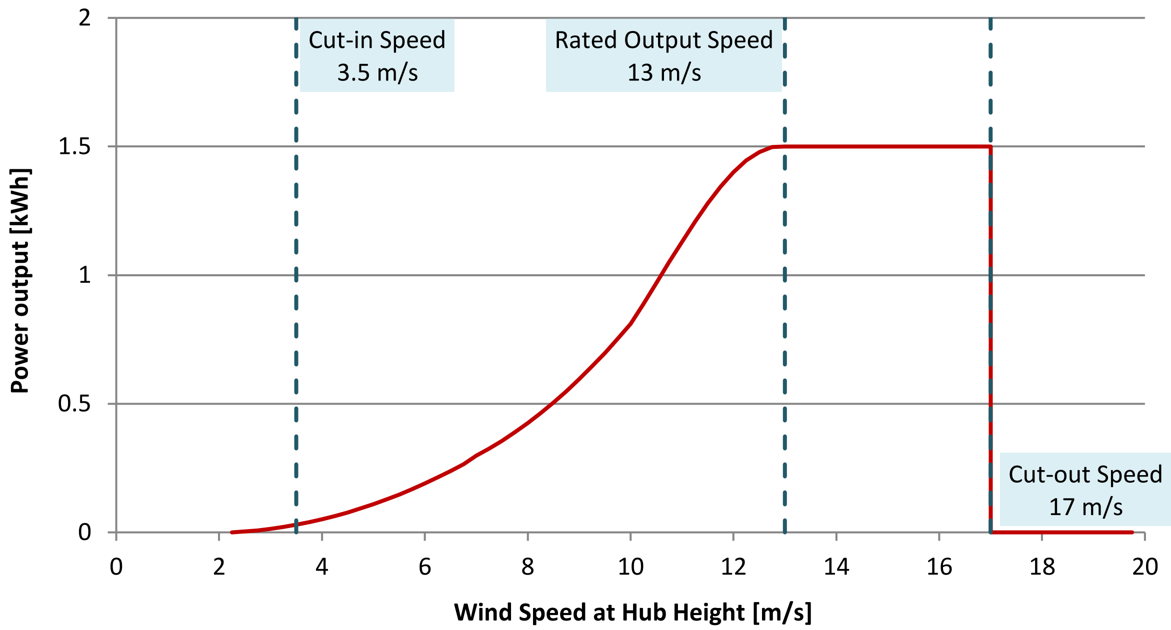

Figure 1-1 Performance curve of the 1.5 kW wind turbine (based on LUVTEC GMBH n.d.).

1.1.2.2 WindModel2

WindModel2 describes a turbine with a hub height of 20 m and a maximum output of 8.5 kW (BRAUN WINDTURBINEN GMBH n.d.). The power output is calculated via Equations (9) to (13) which are derived from the corresponding performance curve (Figure 1-2).

$$E_{Wind} = 0 \qquad v_{hub} \in [0; 2.25] \qquad (9)$$

$$E_{Wind} = 0.0792 * {v_{hub}}^2 - 0.2673 * v_{hub} + 0.2071 \qquad v_{hub} \in]2.25; 7.25[\qquad (10)$$

$$E_{Wind} = 0.0074 * {v_{hub}}^4 - 0.3413 * {v_{hub}}^3 + 5.5998 * {v_{hub}}^2 - 37.701 * v_{hub} + 91.091 \qquad v_{hub} \in [7.25; 12[; \; E_{Wind} \in [0; 8.5] \qquad (11)$$

$$E_{Wind} = 8.5 \qquad v_{hub} \in [12; 13] \qquad (12)$$

$$E_{Wind} = 0 \qquad v_{hub} \in]13; \infty[\qquad (13)$$

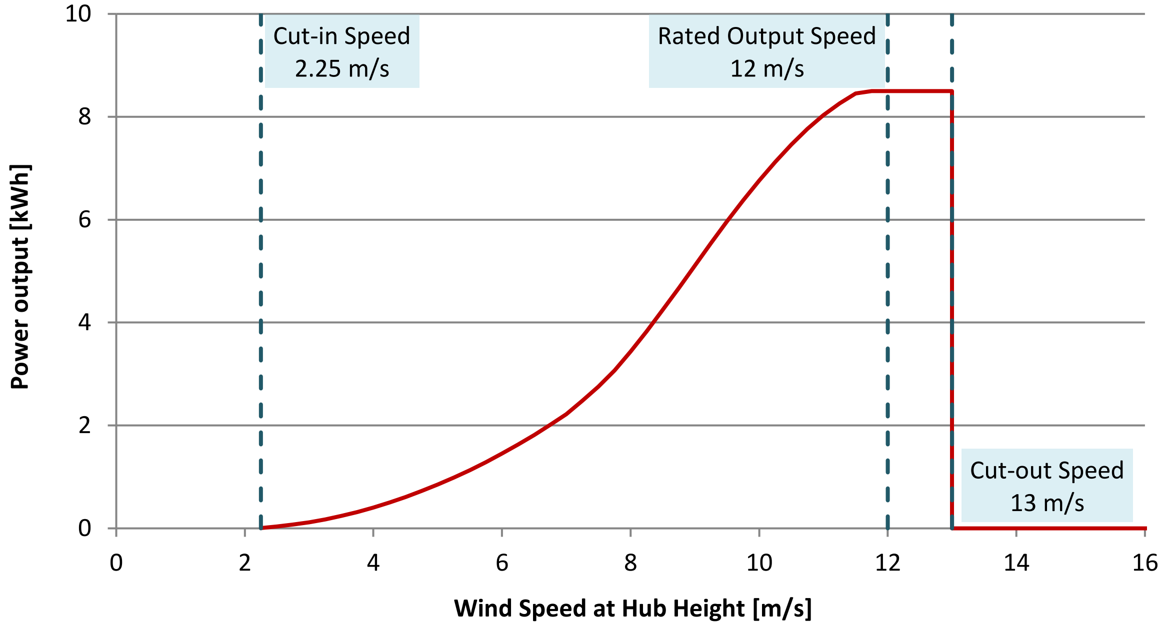

Figure 1-2: Performance curve of the 8.5 kW wind turbine (based on BRAUN WINDTURBINEN GMBH n.d.).

1.1.2.3 WindModel3

WindModel3 describes a turbine with a hub height of 25 m and a maximum output of 12 kW (BRAUN WINDTURBINEN GMBH n.d.). The power output is calculated via Equations (14) to (18)(9) which are derived from the corresponding performance curve (Figure 1-3).

$$E_{Wind} = 0 \qquad v_{hub} \in [0; 2.25] \tag{14}$$

$$E_{Wind} = 0.128 * v_{hub}^2 - 0.4792 * v_{hub} + 0.45 \qquad v_{hub} \in]2.25; 7.25[\tag{15}$$

$$E_{Wind} = -0.0889 * v_{hub}^3 + 2.419 * v_{hub}^2 - 19.642 * v_{hub} + 52.917 \qquad v_{hub} \in [7.25; 12[\,; \; E_{Wind} \in [0; 12] \tag{16}$$

$$E_{Wind} = 12 \qquad v_{hub} \in [12; 13] \tag{17}$$

$$E_{Wind} = 0 \qquad v_{hub} \in]13; \infty[\tag{18}$$

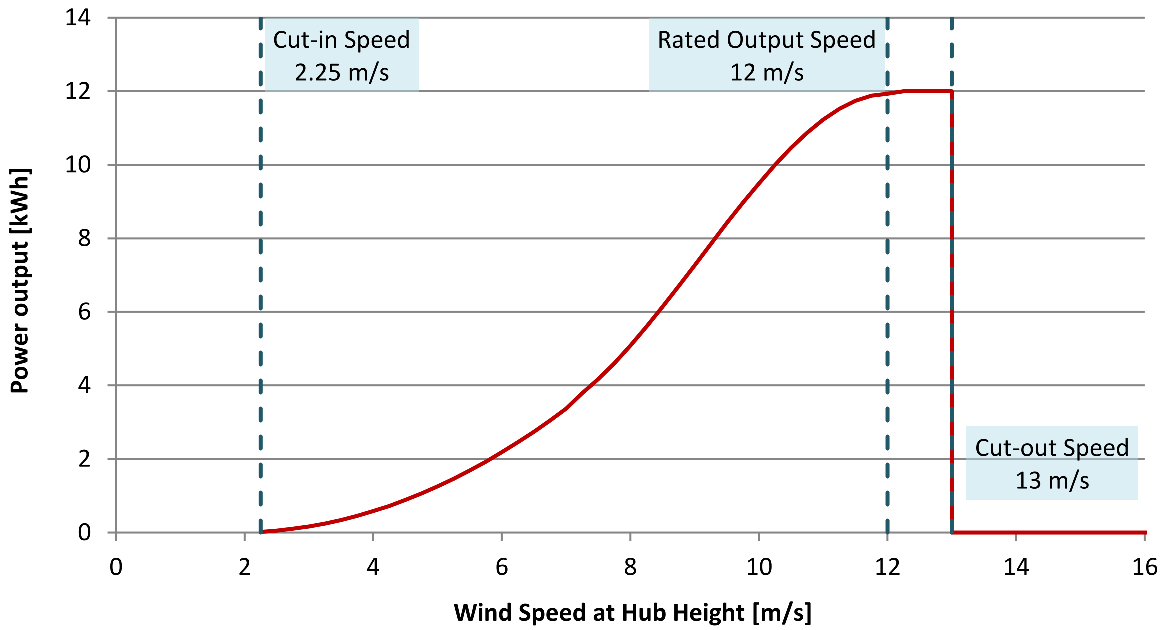

Figure 1-3: Performance curve of the 12 kW wind turbine (based on BRAUN WINDTURBINEN GMBH n.d.).

1.1.2.4 WindModel4

WindModel4 describes a turbine with a hub height of 70 m and a maximum output of 600 kW (BAUER AND MATYSIK n.d.). The power output is calculated via Equations (19) to (22)(9) which are derived from the corresponding performance curve (Figure 1-4).

$$E_{Wind} = 0 \qquad v_{hub} \in [0; 2.5] \qquad (19)$$

$$E_{Wind} = -0.0116 * v_{hub}{}^5 + 0.197 * v_{hub}{}^4 - 0.3087 * v_{hub}{}^3 - 0.46 * v_{hub}{}^2 + 1.879 * v_{hub} - 0.9234 \qquad v_{hub} \in [2.5; 11.5]; \; E_{Wind} \in [0; 600] \qquad (20)$$

$$E_{Wind} = 600 \qquad v_{hub} \in]11.5; 19] \qquad (21)$$

$$E_{Wind} = 0 \qquad v_{hub} \in]19; \infty[\qquad (22)$$

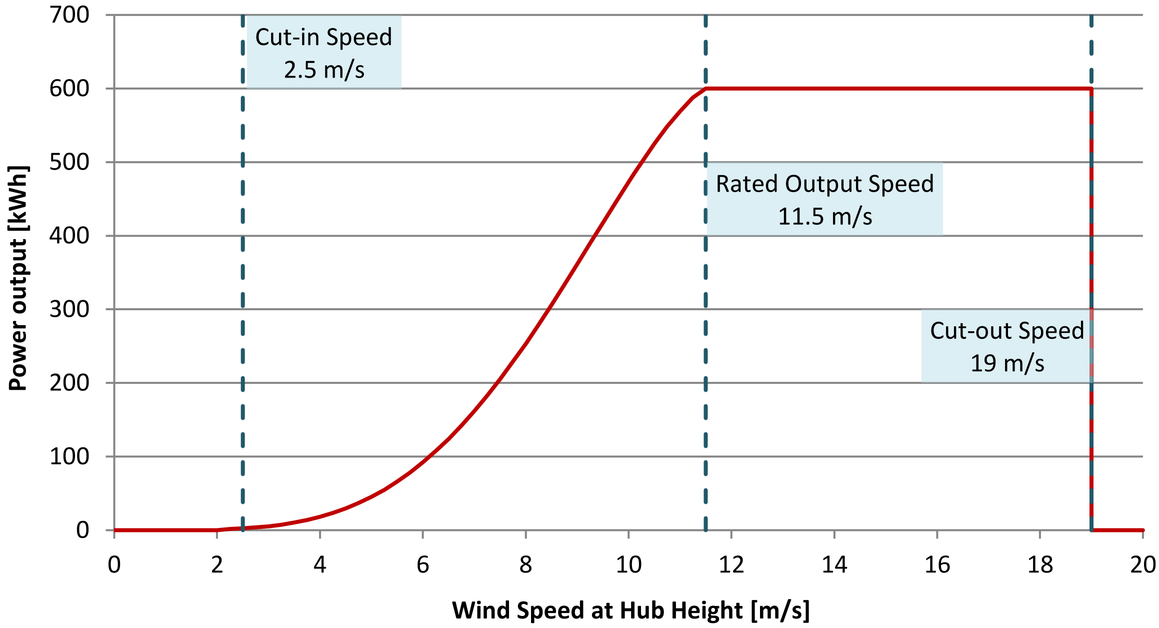

Figure 1-4: Performance curve of the 600 kW wind turbine (based on BAUER AND MATYSIK n.d.).

1.1.2.5 WindModel5

WindModel5 describes a turbine with a hub height of 149 m and a maximum output of 3000 kW (ENERCON 2016). The power output is calculated via Equations (23) to (30) which are derived from the corresponding performance curve (Figure 1-4).

$$E_{Wind} = 0 \qquad v_{hub} \in [0;1] \tag{23}$$

$$E_{Wind} = 3 * v_{hub} - 3 \qquad v_{hub} \in]1;2] \tag{24}$$

$$E_{Wind} = 0.1771 * {v_{hub}}^4 + 0.8495 * {v_{hub}}^3 + 12.247 * {v_{hub}}^2 - 42.64 * v_{hub} + 29.417 \qquad v_{hub} \in]2;5] \tag{25}$$

$$E_{Wind} = -13.056 * {v_{hub}}^3 + 320.17 * {v_{hub}}^2 - 2073.8 * v_{hub} + 4344.3 \qquad v_{hub} \in]5;12[; \; E_{Wind} \in [0;3000] \tag{26}$$

$$E_{Wind} = 3000 \qquad v_{hub} \in [12;27] \tag{27}$$

$$E_{Wind} = -28.708 * {v_{hub}}^3 + 2349.1 * {v_{hub}}^2 - 64194 * v_{hub} + 588810 \qquad v_{hub} \in]27;31[\tag{28}$$

$$E_{Wind} = -18.25 * {v_{hub}}^3 + 1912.3 * {v_{hub}}^2 - 66774 * v_{hub} + 776974 \qquad v_{hub} \in [31;34[; \; E_{Wind} \in [0;3000] \tag{29}$$

$$E_{Wind} = 0 \qquad v_{hub} \in [34;\infty[\tag{30}$$

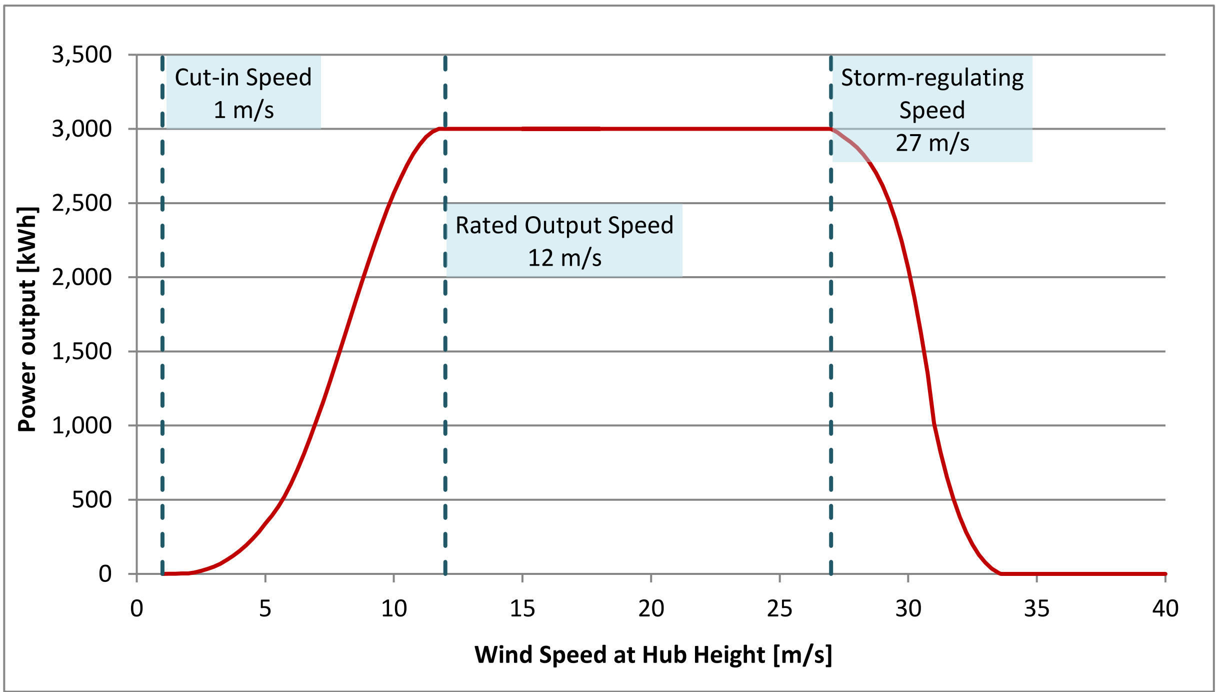

Figure 1-5: Performance curve of the 600 kW wind turbine (based on ENERCON 2016).

1.2 Pre-processing

The pre-processing includes the identification of all existent wind turbines within the region under assessment with their exact positions and technical design. Positions as well as rated output of devices within the EWO region were taken from BAYSTMWI (2015) and ENERGYMAP (2015). Appropriate performance curves were then taken from LUVTEC GMBH (n.d.) and BRAUN WINDTURBINEN GMBH (n.d.). For future turbines, a common turbine type for weak wind regions is chosen that can already be found in wind parks around the EWO region (ENERCON 2016).

1.3 Input Data and Format

The setup file contains the following sections:

- [General]:

Table 1-2: Description of the input-file for the Wind Power Model, Section General

Input Parameters	Description	Unit	Data format
ObjectType	Type of renewable energy = windp	[-]	character
ObjectName	Explicit Name of device	[-]	character
ObjectID	Explicit ID of device	[-]	integer
Position-Proxel	Row and column of position within the model rectangle; divided by multiple spaces	[-]	Integer

- [WindPowerModel]:

Table 1-3: Description of the input-file for the Wind Power Model, Section WindPowerModel

Input Parameters	Description	Unit	Data format
WindPowerActive	Status of the Power Plant	[-]	integer
WindPowerYear, WindPowerMonth, WindPowerDay	Start time of the Power Plant	[-]	integer
WindPowerModel	Type of turbine; Models 1 to 5 (see Sections 1.1.2.1 to 1.1.2.5)	[-]	integer
Hub Height	Hub Height of the turbine	[m]	real
Roughness	Roughness length of ground	[m]	real

Example setup for a wind power plant:

```
General]
ObjectType              windp
ObjectName              E31177010000000005007505353-00000
ObjectId                1
Position-Proxel                  240          183
[end]
```

```
[WindPowerModel]
WindPowerActive        1
WindPowerYear          2003
WindPowerMonth         11
WindPowerDay           25
WindPModel             4
Hub Height             70.0
Roughness              0.16
[end]
```

Figure 1-6: Example of the input file for the Wind Power Model

1.4 Output

The output of the wind power model includes the produced electrical energy in kWh on hourly resolution.

2 Validation

For Validation, time series of measured wind speed and energy output data were provided for one wind turbine situated within the model region (SCHRAMM 2016a, b). The turbine is of the type described in Section 1.1.2.4 with 600 kW rated output and a hub height of 70 m. Wind Speed at hub height

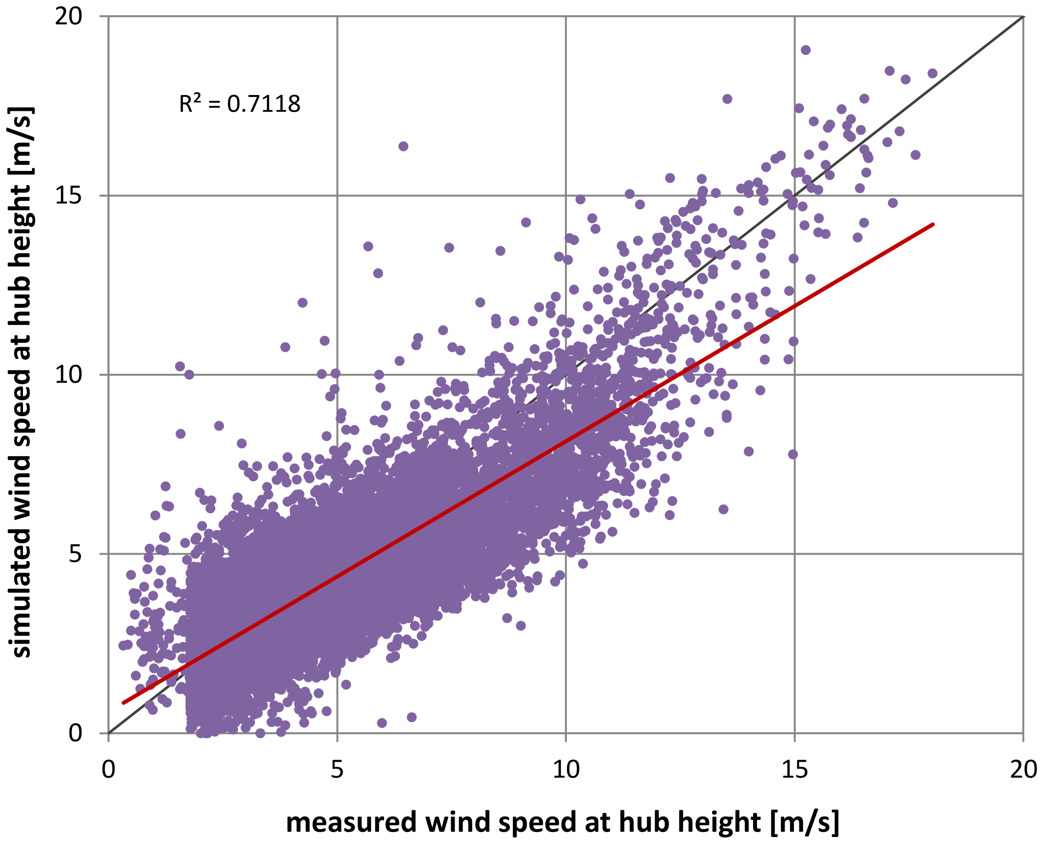

Figure 2-1:

2.1 Monthly Yield

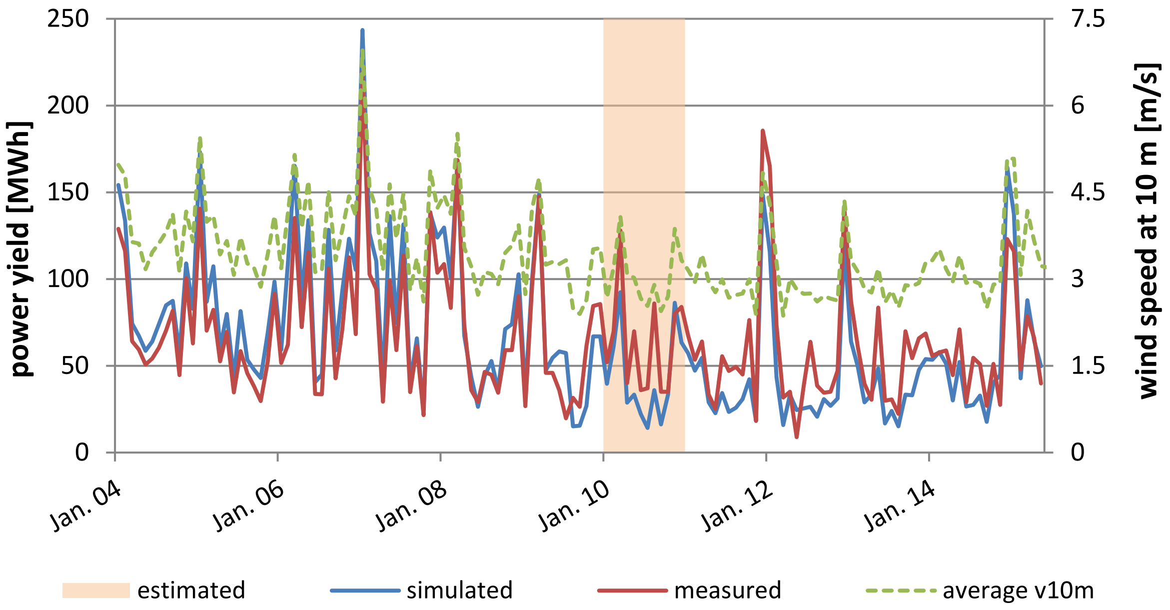

Figure 2-2:

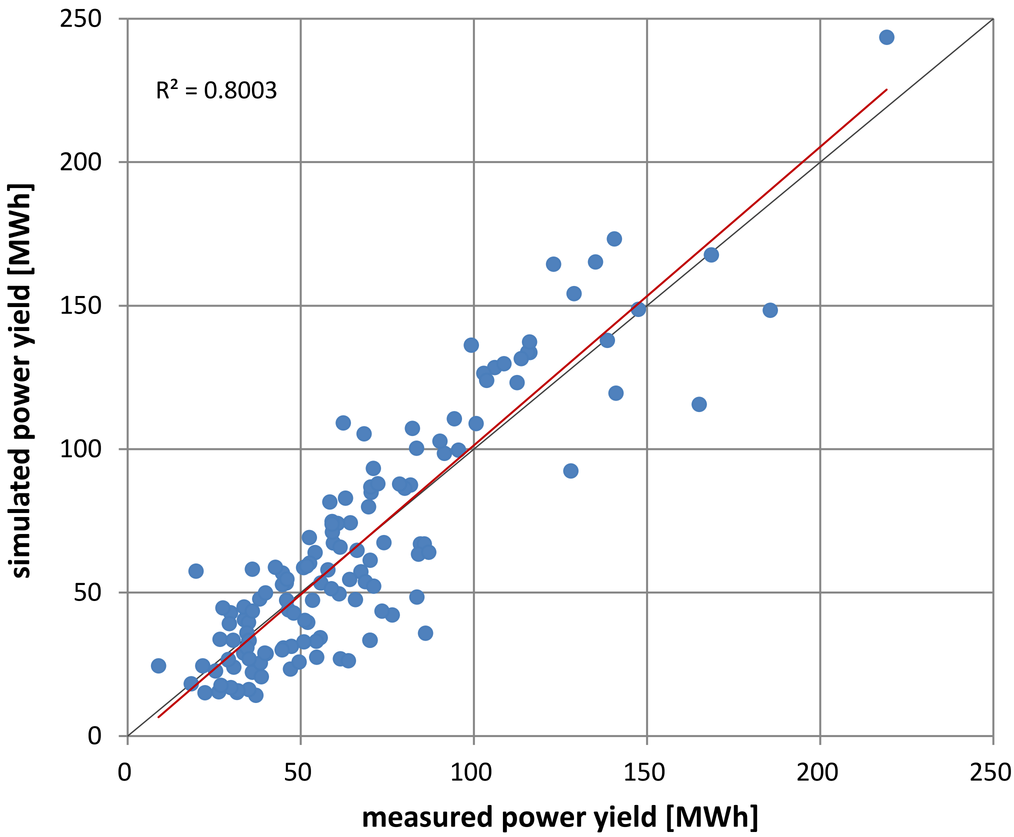

Figure 2-3:

3 Implementation within the Energy Model

The wind power component is completely integrated within the energy model. The work flow within the PROMET model and its components for the calculation of the energy paths is shown in Figure 3-1.

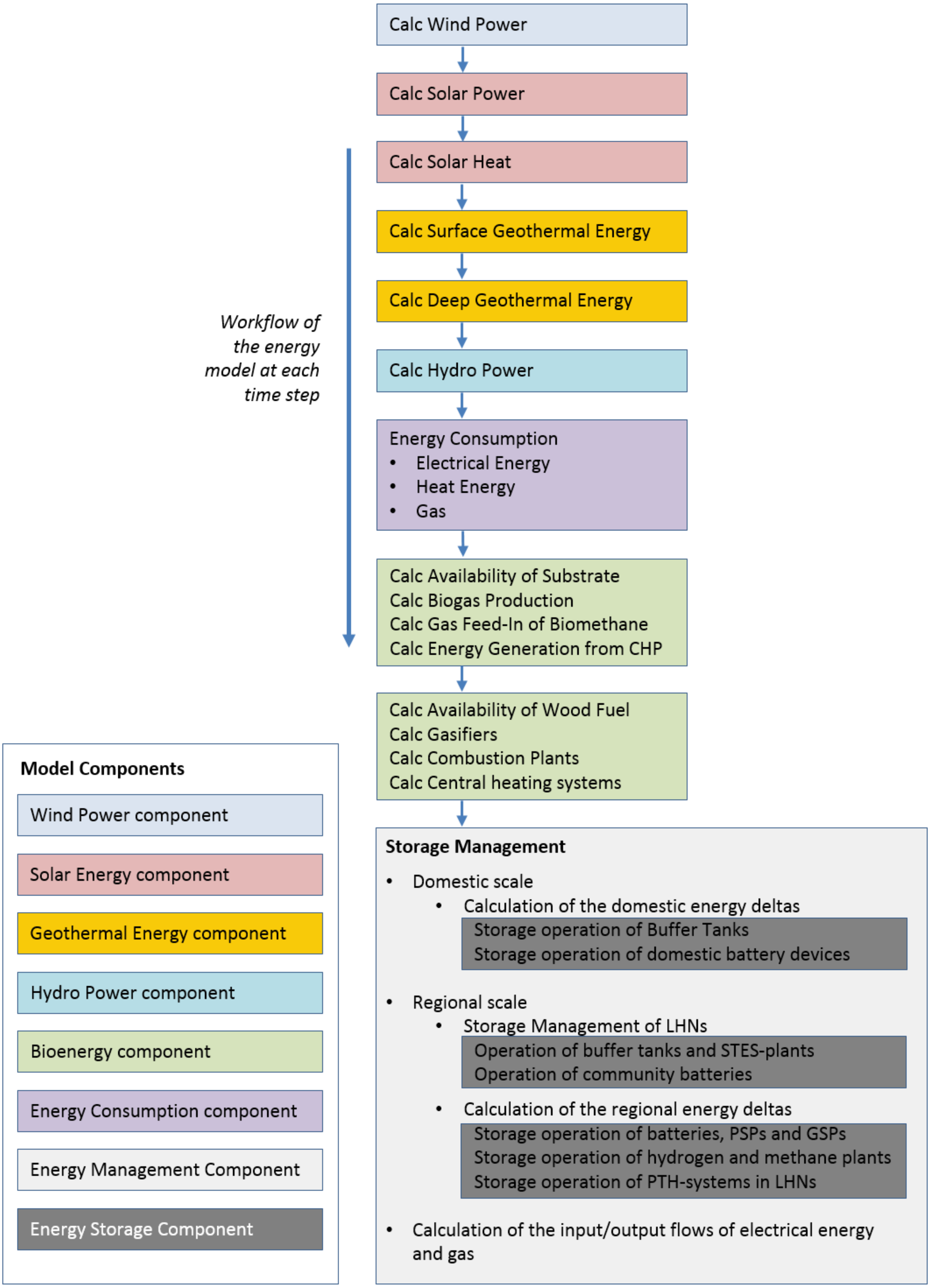

Figure 3-1: Workflow of the Energy model with regarding components

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