



Wind farm in energyPRO

The screenshot displays the energyPRO 3.4 software interface for a wind farm project. The main window is titled "energyPRO 3.4 - WindfarmTest1". The "Input data" tree on the left includes "Ab vaerk leverance", "Energy units", "Wind farm", "Motor1", "Motor2", "Kedler", "Varmelager", "Electricity market", "Operation strategy", "Environment", "Economy", "External conditions", and "Revenues". A context menu is open over "Energy units", listing options: "Add production unit", "Add thermal store", "Add heat blow off", "Load energy unit", "Boiler", "CHP", "Elec. heatpump", "User defined unit", "Absorptions cooler", "Electric cooler", "Wind Farm", "Solar collector", and "Photovoltaic".

The "Wind farm" configuration panel shows the following settings:

- Calculation type: Annual production calculated, Fixed annual production
- Wind speed specification: Time series: WindSpeed 10 meter
- Measure height: 10 m
- Hub height: 80 m
- Hellmann exponent: 0,13
- Advanced (scale power curve): Percentage, Absolute (Max)
- Max. power in original power curve: 9.000 kW
- Scale power curve to: 75 %

The "Power curve" section contains a table and a graph:

Wind speed [m/s]	Power [kW]	Power Modified [kW]
0,50	0,00	0,00
1,50	0,00	0,00
2,50	0,00	0,00
3,50	0,00	0,00
4,50	214,00	160,50
5,50	734,00	550,50
6,50	1.464,00	1.098,00

The graph plots Power [kW] on the y-axis (0 to 9.000) against Wind speed [m/s] on the x-axis (0 to 25). It shows two curves: a red curve representing the original power curve and a green curve representing the scaled power curve. Both curves show a sharp increase in power starting around 4.5 m/s, reaching a plateau at higher wind speeds.

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1. Introduction

The new wind farm in energyPRO is a specialised production unit that makes it much easier to model wind farms than before.

All approaches require that a time series holding wind speed is available and present in the “External conditions”-folder.

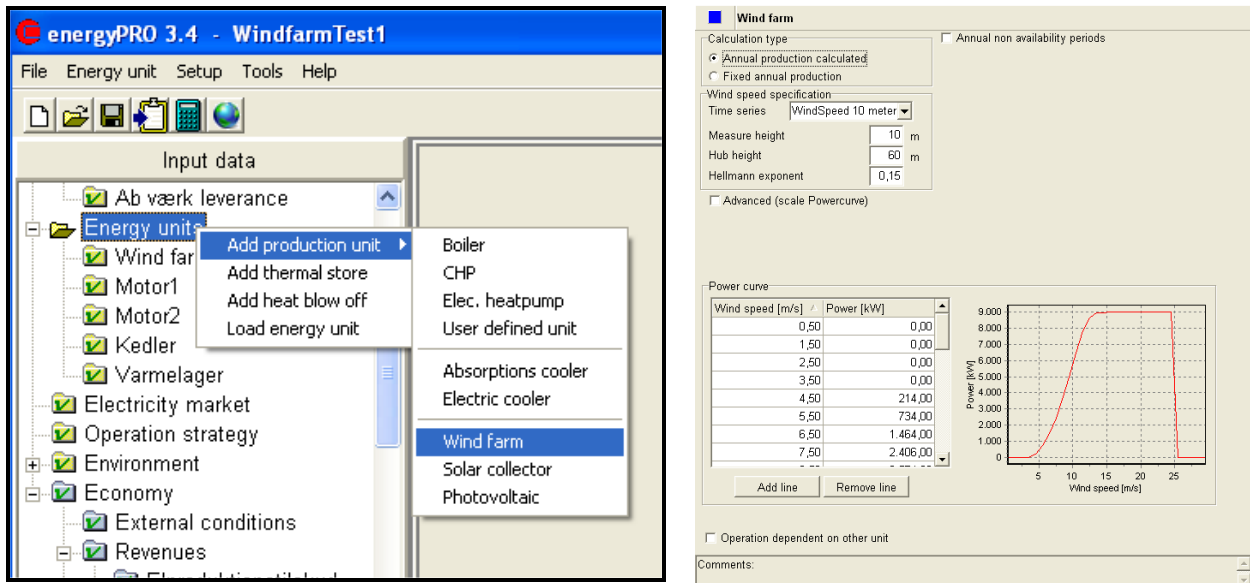


Figure 1.1: Select and specify the production unit - Wind farm

The new wind farm uses an external time series with measured wind speed and a wind farm power curve to calculate electric production from the wind farm. The time series with wind speed must be present in the “External conditions”-folder, and the power curve must be specified in the wind farm editing window.

2. Calculation type

There are two main approaches to calculating wind farms in energyPRO.

1. Annual production calculated, divided into two sub cases
 - a. Farm power curve is used directly
 - b. Power is scaled to another level
2. Fixed annual production (wind speed is scaled)

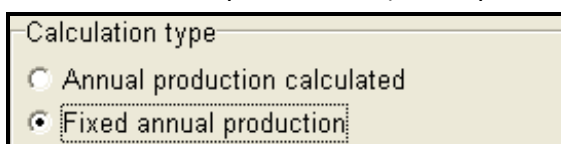


Figure 2.1: Select Calculation type

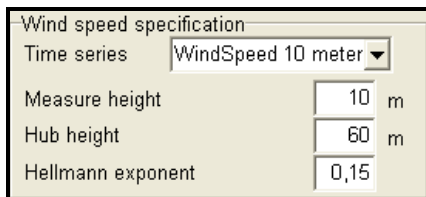
Annual production calculated. In this case the productions from the wind farm is calculated based on the wind speed specification and power curve of the wind farm. As an advanced setting, there are options to scale the power curve and thereby the production.

Fixed annual production. This option serves to distribute a desired annual production given a specified wind farm power curve. All wind speeds specified through “Wind speed specification” (see next section) are scaled by the modification factor that makes agreement between the annual production, the power curve and the wind speeds. This factor is found through iterations.

3. Wind speed specification

The wind speed at hub height is defined through the following parameters, which is used for converting the wind speed in measure height to wind speed at hub height.

1. A time series holding the wind speed time series
2. The measure height of the time series
3. The hub height of the turbines
4. The Hellmann exponent



Wind speed specification	
Time series	WindSpeed 10 meter
Measure height	10 m
Hub height	60 m
Hellmann exponent	0,15

Figure 3.1: Wind speed specification

Ad 1) The time series must be established in External conditions prior to the specification.

4. Specification of power curve

The power curve consists of a data set of values containing the wind speed and the corresponding power output from the turbines. In the calculation, the power output is assumed linear between two data elements. The power curve is specified through a data table and shown on a corresponding graph, see Figure 4.1.

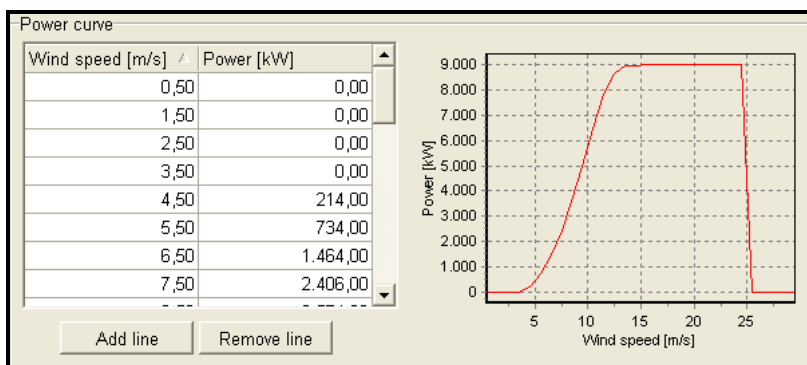


Figure 4.1: The power curve of the wind farm

Specification of power curve

The functionalities of the table are comparable to the other energyPRO tables. This includes unlimited number of values, add line and delete line buttons. Data is added by typing data into the table or it can be pasted via the clipboard. It is possible to copy a calculated wind farm curve from WindPro® via the clipboard to the wind farm power curve in energyPRO, see Figure 4.2.

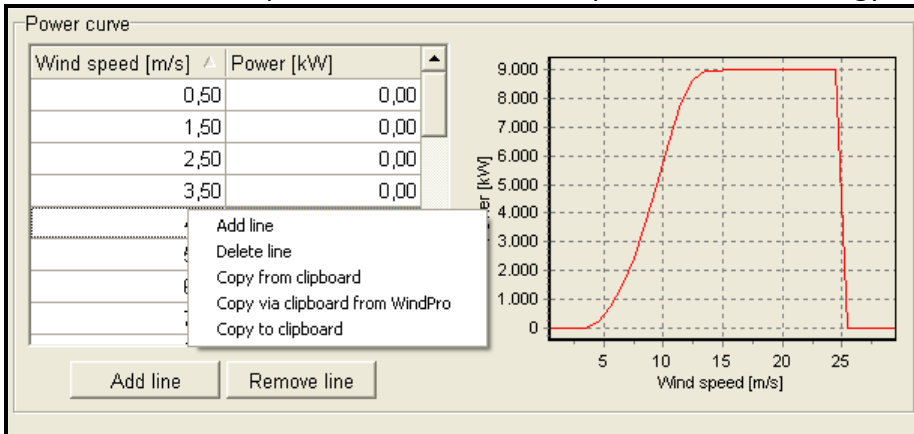


Figure 4.2: The power curve. Values can be copied via clipboard, including wind farm power curve calculated in WindPro

4.1 Annual production calculated

4.1.1 Annual production calculated, not advanced

Figure 4.3 shows the content of the wind farm editing-window if “Annual production calculated” is selected. This window contain the data described in this window, plus an advanced option.

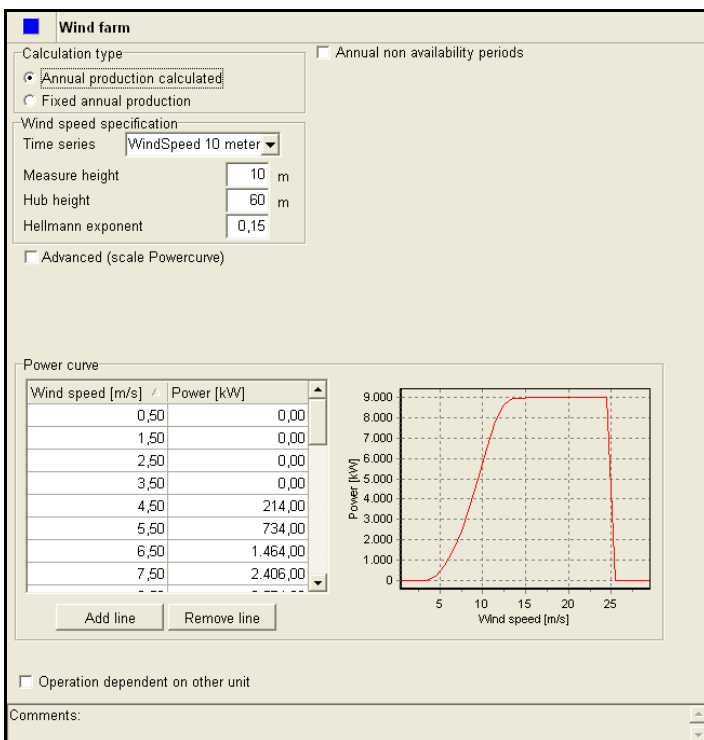


Figure 4.3: Wind farm, “Annual production calculated”, not advanced

4.1.2 Annual production calculated (power curve scaled).

An example of this shown in Figure 4.4. Notice that the power curve now has a new resulting power curve both in the table presentation and in the graphic representation. There are two variants. It is possible to scale the power curve using a percentage or a new max. power curve value, see Figure 4.4 and Figure 4.5.

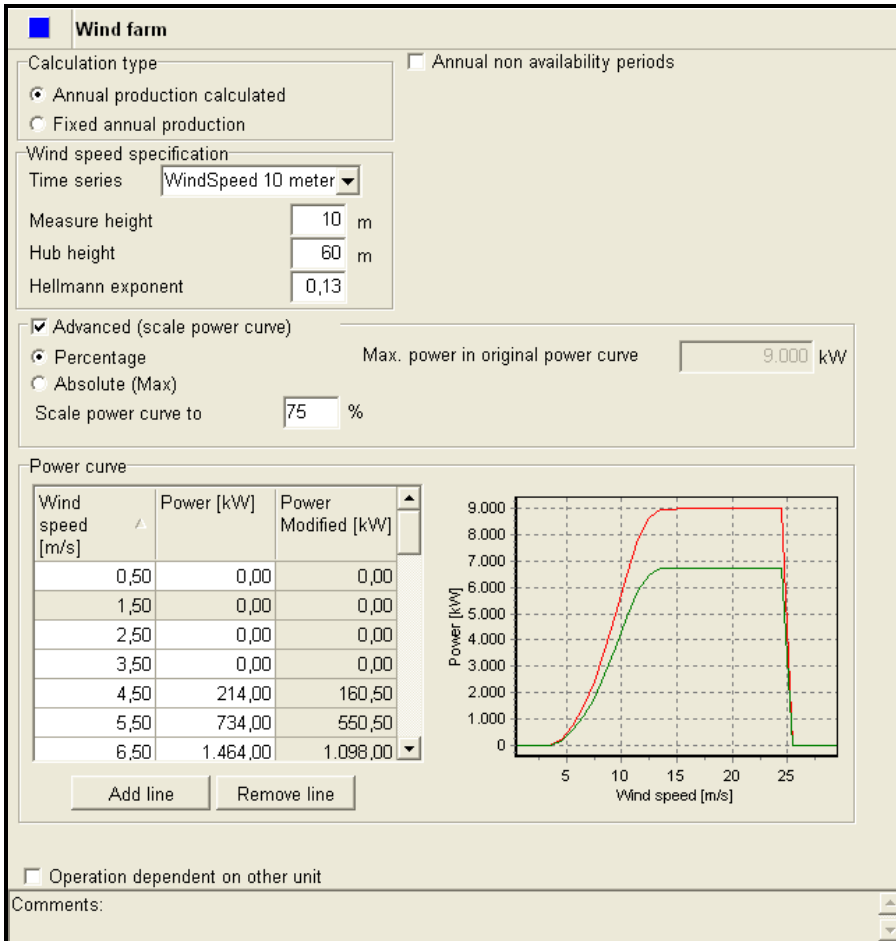


Figure 4.4: Wind farm, “Annual production calculated”, power curve scaled with percentage

Specification of power curve

Wind farm

Calculation type
 Annual production calculated
 Fixed annual production

Annual non availability periods

Wind speed specification
Time series: WindSpeed 10 meter

Measure height: 10 m
Hub height: 60 m
Hellmann exponent: 0,13

Advanced (scale power curve)
 Percentage Max. power in original power curve: 9.000 kW
 Absolute (Max)
Max. power in modified power curve: 7.000 kW

Power curve

Wind speed [m/s]	Power [kW]	Power Modified [kW]
0,50	0,00	0,00
1,50	0,00	0,00
2,50	0,00	0,00
3,50	0,00	0,00
4,50	214,00	166,44
5,50	734,00	570,89
6,50	1.464,00	1.138,67

Add line Remove line

Operation dependent on other unit

Comments:

Figure 4.5: Wind farm, “Annual production calculated”, power curve scaled with max power curve value

4.2 Fixed Annual production

If Fixed annual production is selected then the Annual production and the wind farm power curve is specified (e.g. calculated in WindPro). Given the power curve and a stated annual production all wind speed values are scaled by a factor. This factor is calculated, and is used when calculating the production at any time. See the description in section 5.

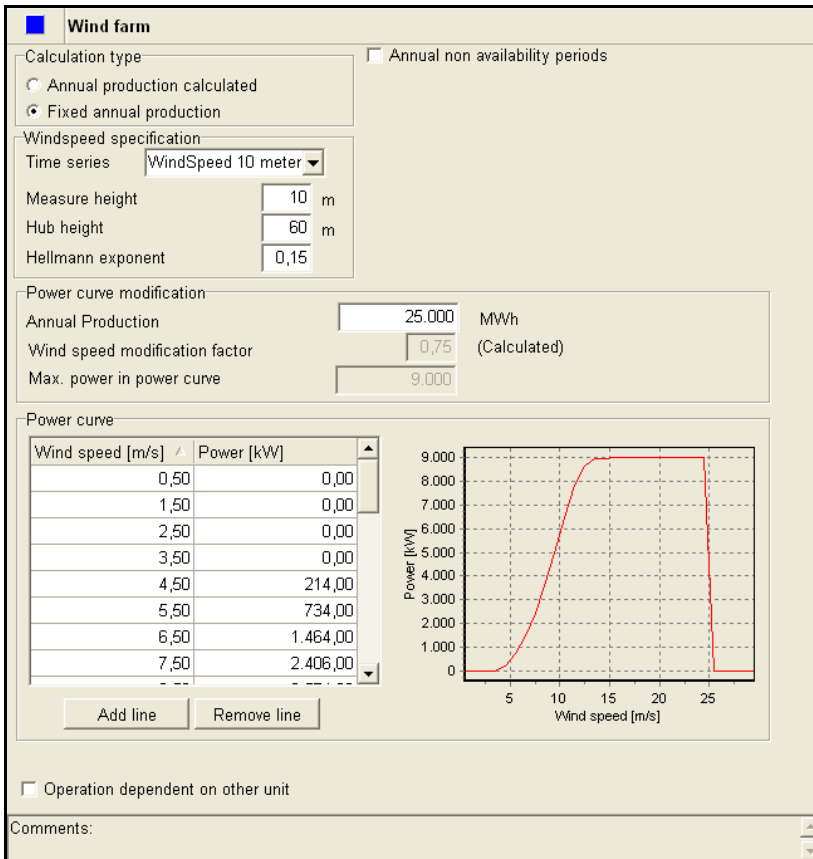


Figure 4.6: Fixed annual production (Scaling wind speed)

5. Method of wind farm calculation in energyPRO

The wind farm model in energyPRO cover three different cases.

1. Annual production calculated
 - a. Power curve used directly
 - b. Power curve is scaled to another level
2. Fixed annual production (wind speed is scaled)

5.1 Definitions

$WS_m(t)$	= Wind speed measured (m/s) at time t
$WS_c(t)$	= Wind speed calculated (m/s) at time t
H_m	= Height of measurements (m)
H_h	= Hub Height (m)
α	= Hellmann coefficient
m_f	= Wind speed modification factor
$PC(WS_c(t))$	= The power from the power curve based on the calculated wind speed at hub height and linear interpolation on power curve.
P_{MaxPC}	= Max power value found in power curve
P_{Max}	= Max Power stated
$P(t)$	= Production at time t
$P_{annualDesired}$	= Annual production desired (MWh)
$P_{annualCalc}$	= Annual production calculated (MWh)

5.2 Mathematical description

5.2.1 Wind speed at hub height

Calculated wind speed at hub height in cases 1a and 1b.

$$(1) WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m} \right)^\alpha$$

Calculated wind speed at hub height in case 2.

$$(2) WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m} \right)^\alpha * m_f,$$

Where the modification factor is found through iterations

5.2.2 Calculation of production at time t

$$(3) P(t) = PC(WS_c(t)) \quad (\text{Case 1a})$$

$$(4) P(t) = PC(WS_c(t)) * P_{\max} / P_{\max PC} \quad (\text{Case 1b})$$

$$(5) P(t) = PC(WS_c(t)) \quad (\text{Case 2})$$

Where $PC(WS_c(t))$ return then power from the power curve based on the calculated wind speed at hub height and linear interpolation on power curve.

5.2.3 Calculation of wind modification factor

$$(6) P_{\text{annualCalc}} = \sum_{t=0}^{t=H_{\text{year}}} PC(WS_c(t)) * \Delta T, \text{ where } WS_c(t) = WS_m(t) * \left(\frac{H_h}{H_m} \right)^\alpha * m_f$$

Start guess $m_{f=1}$

In each iteration is the annual production calculated (6) and compared with the desired value

Method of wind farm calculation in energyPRO

If $P_{\text{annualCalc}} > P_{\text{annualDesired}}$ then decrease m_f

If $P_{\text{annualCalc}} < P_{\text{annualDesired}}$ then increase m_f

This is repeated until

$P_{\text{annualCalc}} \cong P_{\text{annualDesired}}$

then m_f is found.