RETScreen® International

Clean Energy Decision Support Centre

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CLEAN ENERGY PROJECT ANALYSIS:
RETSCREEN® ENGINEERING & CASES TEXTBOOK

CANMET Energy Technology Centre - Varennes (CETC)

In collaboration with:

NASA

UNEP

GEF

WIND ENERGY PROJECT ANALYSIS

CHAPTER

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WIND ENERGY PROJECT ANALYSIS CHAPTER

Clean Energy Project Analysis: RETScreen® Engineering & Cases is an electronic textbook for professionals and university students. This chapter covers the analysis of potential wind energy projects using the RETScreen® International Clean Energy Project Analysis Software, including a technology background and a detailed description of the algorithms found in the RETScreen® Software. A collection of project case studies, with assignments, worked-out solutions and information about how the projects fared in the real world, is available at the RETScreen® International Clean Energy Decision Support Centre Website www.retscreen.net.

1 WIND ENERGY BACKGROUND[1]

The kinetic energy in the wind is a promising source of renewable energy with significant potential in many parts of the world. The energy that can be captured by wind turbines is highly dependent on the local average wind speed. Regions that normally present the most attractive potential are located near coasts, inland areas with open terrain or on the edge of bodies of water. Some mountainous areas also have good potential. In spite of these geographical limitations for wind energy project siting, there is ample terrain in most areas of the world to provide a significant portion of the local electricity needs with wind energy projects (Rangi et al., 1992).

Figure 1:
39.6 MW Central-Grid Windfarm in Spain.

Photo Credit:
Photo © BONUS Energy A/S

1. Some of the text in this "Background" description comes from the following two CANMET supported reports: ***Wind Energy Basic Information***, Backgrounder published by the Canadian Wind Energy Association (CanWEA), and, Rangi, R., Templin, J., Carpentier, M. and Argue, D., ***Canadian Wind Energy Technical and Market Potential***, EAETB, Energy, Mines and Resources Canada (CANMET), ON, Canada, October 1992.

The world-wide demand for wind turbines has been growing rapidly over the last 15 years. During 2001 alone the wind energy industry installed close to 5,500 MW of new generating capacity. More than 24,000 MW of wind energy capacity is now estimated to be in operation around the world (Wind Power Monthly, 2001). Much of this demand has been driven by the need for electric power plants that use "cleaner fuels." Windfarms that use multiple turbines are being constructed in the multi-megawatt range, as depicted in ***Figure 1***. Over the last decade, typical individual turbine sizes have increased from around 100 kW to 1 MW or more of electricity generation capacity, with some wind energy projects now even being developed offshore, as shown in ***Figure 2***. The result of all this progress is that, in some areas of the world, large-scale wind energy projects now generate electricity at costs competitive with conventional power plants (e.g. nuclear, oil and coal).

Figure 2:

2 MW Wind Turbines at 40 MW Offshore Windfarm in Denmark.

Photo Credit:
Photo © BONUS Energy A/S

In addition to these larger scale applications, there are a number of other applications for wind turbines, such as medium scale applications on isolated-grids and off-grid uses for pumping water and providing smaller amounts of electricity for stand-alone battery charging applications.

Wind energy projects are generally more financially viable in "windy" areas. This is due to the fact that the power potential in the wind is related to the cube of the wind speed. However, the power production performance of a practical wind turbine is typically more proportional to the square of the average wind speed. The difference is accounted for by the aerodynamic, mechanical and electrical conversion characteristics and efficiencies of the wind turbines. This means that the energy that may be produced by a wind turbine will increase by about 20% for each 10% increase in wind speed. Wind energy project siting is critical to a financially viable venture. It is important to note that since the human sensory perception of the wind is usually based on short-term observations of climatic extremes such as wind storms and wind chill impressions, either of these "wind speeds" might be wrongly interpreted as representative of a windy site. Proper wind resource assessment is a standard and important component for most wind energy project developments.

1.1 Description of Wind Turbines

Wind turbine technology has reached a mature status during the past 15 years as a result of international commercial competition, mass production and continuing technical success in research and development (R&D). The earlier concerns that wind turbines were expensive and unreliable have largely been allayed. Wind energy project costs have declined and wind turbine technical availability is now consistently above 97%. Wind energy project plant capacity factors have also improved from 15% to over 30% today, for sites with a good wind regime (Rangi et al., 1992).

Modern wind energy systems operate automatically. The wind turbines depend on the same aerodynamic forces created by the wings of an aeroplane to cause rotation. An anemometer that continuously measures wind speed is part of most wind turbine control systems. When the wind speed is high enough to overcome friction in the wind turbine drivetrain, the controls allow the rotor to rotate, thus producing a very small amount of power. This cut-in wind speed is usually a gentle breeze of about 4 m/s. Power output increases rapidly as the wind speed rises. When output reaches the maximum power the machinery was designed for, the wind turbine controls govern the output to the rated power. The wind speed at which rated power is reached is called the rated wind speed of the turbine, and is usually a strong wind of about 15 m/s. Eventually, if the wind speed increases further, the control system shuts the wind turbine down to prevent damage to the machinery. This cut-out wind speed is usually around 25 m/s.

The major components of modern wind energy systems typically consist of the following:

- Rotor, with 2 or 3 blades, which converts the energy in the wind into mechanical energy onto the rotor shaft;
- Gearbox to match the slowly turning rotor shaft to the electric generator;
- Tall tower which supports the rotor high above the ground to capture the higher wind speeds;
- Solid foundation to prevent the wind turbine from blowing over in high winds and/or icing conditions (CanWEA, 1996); and
- Control system to start and stop the wind turbine and to monitor proper operation of the machinery.

Figure 3 illustrates the configuration of a typical "Horizontal Axis Wind Turbine" or HAWT wind energy system. A "Vertical Axis Wind Turbine" or VAWT is an equally viable alternative design, although it is not as common as the HAWT design in recent projects implemented around the world.

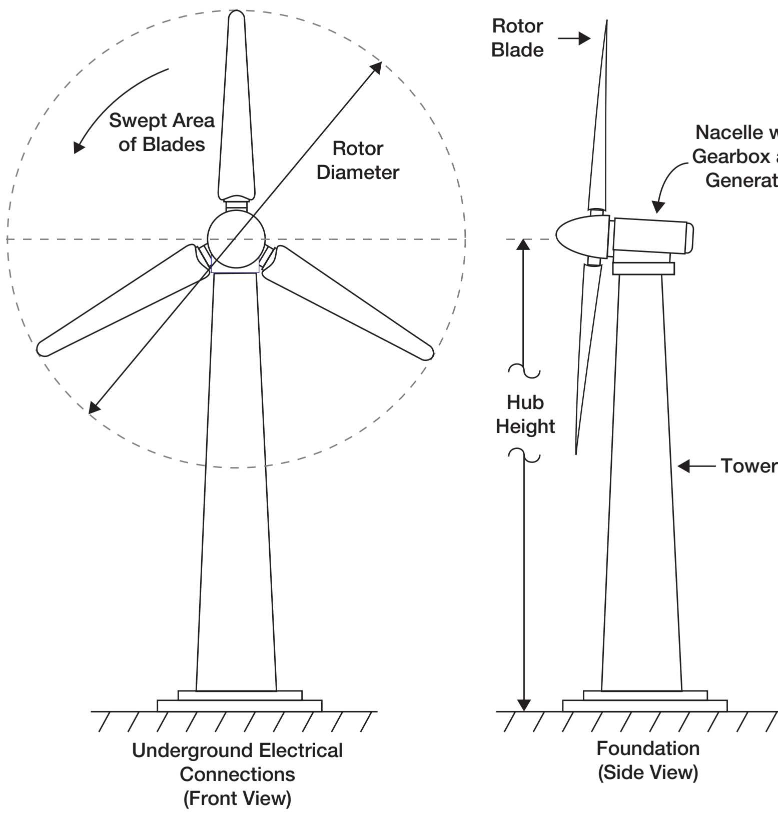

Figure 3:

Wind Energy System Schematic.

1.2 Wind Energy Application Markets

Wind energy markets can be classified based on the end-use application of the technology. Wind energy projects are common for off-grid applications. However, the largest market potential for wind energy projects is with on-grid (or grid-connected) applications.

1.2.1 Off-grid applications

Historically, wind energy was most competitive in remote sites, far from the electric grid and requiring relatively small amounts of power, typically less than 10 kW. In these off-grid applications, wind energy is typically used in the charging of batteries that store the energy captured by the wind turbines and provides the user with electrical energy on demand, as depicted in ***Figure 4***. Water pumping, where water, rather than energy, can be stored for future use, is also a key historical application of wind energy. The key competitive area for wind energy in remote off-grid power applications is against electric grid extension, primary (disposable) batteries, diesel, gas and thermoelectric generators. Wind energy is also competitive in water pumping applications (Leng et al., 1996).

Figure 4:
10 kW Off-Grid Wind Turbine in Mexico.

Photo Credit:
Charles Newcomber/NREL Pix

1.2.2 On-grid applications

In on-grid applications the wind energy system feeds electrical energy directly into the electric utility grid. Two on-grid application types can be distinguished.

1. Isolated-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 10 kW to 200 kW.

2. Central-grid electricity generation, with wind turbine generation capacity typically ranging from approximately 200 kW to 2 MW.

RETScreen® International Wind Energy Project Model

The RETScreen® International Wind Energy Project Model can be used world-wide to easily evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for central-grid, isolated-grid and off-grid wind energy projects, ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems.

Isolated-grids

Isolated-grids are common in remote areas. Electricity generation is often relatively expensive due to the high cost of transporting diesel fuel to these isolated sites. However, if the site has good local winds, a small wind energy project could be installed to help supply a portion of the electricity requirements. These wind energy projects are normally referred to as wind-diesel hybrid systems. The wind energy system's primary role is to help reduce the amount of diesel fuel consumption. A wind-diesel hybrid system is shown in ***Figure 5***.

Figure 5:
50 kW Isolated-Grid Wind Turbine in the Arctic.

Photo Credit:
Phil Owens/Nunavut Power Corp.

Central-grids

Central-grid applications for wind energy projects are becoming more common. In relatively windy areas, larger scale wind turbines are clustered together to create a windfarm with capacities in the multi-megawatt range. The land within the windfarm is usually used for other purposes, such as agriculture or forestry. Another common approach for wind energy project development includes the installation of one or more larger scale wind turbines by individuals, businesses or co-operatives.

A windfarm, as depicted in ***Figure 6***, consists of a number of wind turbines (which are often installed in rows perpendicular to the wind direction), access roads, electrical interconnections and a substation, a monitoring and control system and a maintenance building for the larger farms. The development of a wind energy project includes the determination of the wind resource, the acquisition of all authorisations and permits, the design and specification of the civil, electrical and mechanical infrastructure, the layout of the wind turbines, the purchasing of the equipment, the construction and the commissioning of the installation. Construction involves preparing the site, grading roads, building turbine foundations, installing the electrical collection lines and transformers, erecting the turbines, and construction of the substation and building.

Figure 6:

Components of a Windfarm in the United States.

Photo Credit:
Warren Gretz/NREL Pix

The wind resource assessment and approvals for a windfarm are often the longest activities in the development of the wind energy project. These can take up to 4 years in the case of a large windfarm requiring a comprehensive environmental impact study. The construction itself can normally be completed within one year. The precise determination of the wind resource at a given site is one of the most important aspects in the development of a wind energy project as the available wind resource at the project site can dramatically impact the cost of wind energy production. In the case where a pre-feasibility study indicates that a proposed wind energy project could be financially viable, it is typically recommended that a project developer take at least a full year of wind measurements at the exact location where the wind energy project is going to be installed (Brothers, 1993), (CanWEA, 1996) and (Lynette et al., 1992). ***Figure 7*** shows the installation of a 40 m tall meteorological mast at the CANMET Energy Technology Centre - Varennes in Canada.

Figure 7:

Installation of a 40 m Meteorological Mast.

Photo Credit:

GPCo Inc.

For very small-scale projects (e.g. off-grid battery charging and water pumping), the cost of wind monitoring could actually be higher than the cost to purchase and install a small wind turbine. In this case a detailed wind resource assessment would normally not be completed.

2 RETSCREEN WIND ENERGY PROJECT MODEL

The RETScreen® International Wind Energy Project Model can be used world-wide to easily evaluate the energy production, life-cycle costs and greenhouse gas emissions reduction for central-grid, isolated-grid and off-grid wind energy projects, ranging in size from large scale multi-turbine wind farms to small scale single-turbine wind-diesel hybrid systems.

Six worksheets (*Energy Model, Equipment Data, Cost Analysis, Greenhouse Gas Emission Reduction Analysis (GHG Analysis), Financial Summary* and *Sensitivity and Risk Analysis (Sensitivity)*) are provided in the Wind Energy Project Workbook file.

The ***Energy Model*** and ***Equipment Data*** worksheets are completed first. The ***Cost Analysis*** worksheet should then be completed, followed by the ***Financial Summary*** worksheet. The ***GHG Analysis*** and ***Sensitivity*** worksheets are optional analysis. The *GHG Analysis* worksheet is provided to help the user estimate the greenhouse gas (GHG) mitigation potential of the proposed project. The *Sensitivity* worksheet is provided to help the user estimate the sensitivity of important financial indicators in relation to key technical and financial parameters. In general, the user works from top-down for each of the worksheets. This process can be repeated several times in order to help optimise the design of the wind energy project from an energy use and cost standpoint.

To help the user characterise a wind energy system before evaluating its cost and energy performance, some values are suggested, such as "suggested wind energy absorption rate" for projects located on isolated-grid and off-grid. Suggested or estimated values are based on input parameters and can be used as a first step in the analysis and are not necessarily the optimum values.

This section describes the various algorithms used to calculate, on an annual basis, the energy production of wind energy systems in RETScreen. A flowchart of the algorithms is shown in ***Figure 8***. The calculation of the energy curve and the unadjusted energy production is described in *Section 2.1.* Gross energy production, which takes into account effects of temperature and atmospheric pressure, is calculated in *Section 2.2.* Calculation of net energy production (i.e. taking into account various losses) and renewable energy delivered is covered in *Section 2.3.* A validation of the RETScreen Wind Energy Project Model is presented in *Section 2.4.*

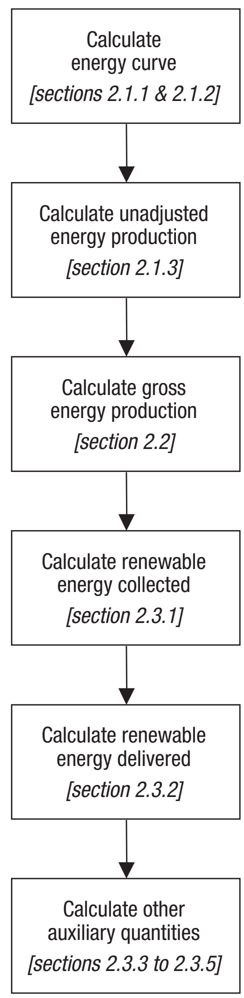

Figure 8:
Wind Energy Model Flowchart.

The main limitations of the model are that the stand-alone wind energy projects requiring energy storage currently cannot be evaluated, and that the model has not yet been validated for vertical axis wind energy systems. Also, the model addresses primarily "low penetration" technologies. To properly evaluate "high penetration" technologies currently under development for isolated diesel-grid applications, the user will need to carefully evaluate the "wind energy absorption rate" used and will likely require further information. However, for the majority of the wind energy capacity being installed around the world today, these limitations are without consequence.

2.1 Unadjusted Energy Production

RETScreen calculates the unadjusted energy production from the wind turbines. It is the energy that one or more wind turbines will produce at standard conditions of temperature and atmospheric pressure. The calculation is based on the energy production curve of the selected wind turbine (entered in the *Equipment Data* worksheet) and on the average wind speed at hub height for the proposed site.

2.1.1 Wind speed distribution

Wind speed distribution, when required in the model (see *Section 2.1.2*), is calculated in RETScreen as a Weibull probability density function. This distribution is often used in wind energy engineering, as it conforms well to the observed long-term distribution of mean wind speeds for a range of sites. In some cases the model also uses the Rayleigh wind speed distribution, which is a special case of the Weibull distribution, where the shape factor (described below) is equal to 2.

The Weibull probability density function expresses the probability $p(x)$ to have a wind speed x during the year, as follows (Hiester and Pennell, 1981):

$$p(x) = \left(\frac{k}{C}\right)\left(\frac{x}{C}\right)^{k-1} \exp\left[-\left(\frac{x}{C}\right)^{k}\right] \qquad (1)$$

This expression is valid for $k > 1$, $x \geq 0$, and $C > 0$. k is the shape factor, specified by the user. The shape factor will typically range from 1 to 3. For a given average wind speed, a lower shape factor indicates a relatively wide distribution of wind speeds around the average while a higher shape factor indicates a relatively narrow distribution of wind speeds around the average. A lower shape factor will normally lead to a higher energy production for a given average wind speed. C is the scale factor, which is calculated from the following equation (Hiester and Pennell, 1981):

$$C = \frac{\bar{x}}{\Gamma\left(1 + \frac{1}{k}\right)} \qquad (2)$$

where $\bar{x}$ is the average wind speed value and Γ is the gamma function.

In some cases, the model will calculate the wind speed distribution from the wind power density at the site rather than from the wind speed. The relations between the wind power density WPD and the average wind speed $\bar{v}$ are:

$$WPD = \sum_{x=0}^{x=25} 0.5\,\rho\;x^3\,p(x) \tag{3}$$

$$\bar{v} = \sum_{x=0}^{x=25} x\;p(x) \tag{4}$$

where ρ is the air density and $p(x)$ is the probability to have a wind speed x during the year.

2.1.2 Energy curve

The energy curve data is the total amount of energy a wind turbine produces over a range of annual average wind speeds. In RETScreen, the energy curve is specified over the range of 3 to 15 m/s annual average wind speed, and is displayed graphically in the *Equipment Data* worksheet.

The user can specify the energy curve data by choosing among the three following data sources: *Standard*, *Custom* and *User-defined*. For the standard and custom cases, the model uses the wind turbine power curve data entered by the user and the Weibull probability function described in *Section 2.1.1* to calculate the energy curve data. In the *User-defined* case, the user directly enters the energy curve data.

In the Standard and Custom cases, the user specifies the wind turbine power curve as a function of wind speed in increments of 1 m/s, from 0 m/s to 25 m/s. Each point on the energy curve, $E_{\bar{v}}$, is then calculated as:

$$E_{\bar{v}} = 8760 \sum_{x=0}^{25} P_x\;p\left(x\right) \tag{5}$$

where $\bar{v}$ is the mean wind speed considered ($\bar{v}$=3, 4, …, 15 m/s), P_x is the turbine power at wind speed x, and $p\left(x\right)$ is the Weibull probability density function for wind speed x, calculated for an average wind speed $\bar{v}$.

2.1.3 Unadjusted energy production

The unadjusted energy production is the energy produced by the turbines at standard conditions of temperature and atmospheric pressure. The calculation is based on the average wind speed at hub height for the proposed site. Wind speed at hub height is usually significantly higher than wind speed measured at anemometer height due to wind shear. The model uses the following power law equation to calculate the average wind speed at hub height [Gipe, 1995]:

$$\frac{\bar{V}}{\bar{V}_0} = \left(\frac{H}{H_0}\right)^{\alpha} \qquad (6)$$

where $\bar{V}$ is the average wind speed at hub height H, $\bar{V}_0$ is the wind speed at anemometer height H_0, and α is the wind shear exponent. Values of H, H_0, $\bar{V}_0$ and α are specified by the user[2].

Once the annual average wind speed at hub height $\bar{V}$ is calculated, the unadjusted energy production E_U is calculated simply by interpolating the energy curve from *Section 2.1.2* at the value $\bar{V}$.

2.2 Gross Energy Production

Gross energy production is the total annual energy produced by the wind energy equipment, before any losses, at the wind speed, atmospheric pressure and temperature conditions at the site. It is used in RETScreen to determine the renewable energy delivered (*Section 2.3*). Gross energy production E_G is calculated through:

$$E_G = E_U \;\; c_H \;\; c_T \qquad (7)$$

where E_U is the unadjusted energy production, and c_H and c_T are the pressure and temperature adjustment coefficients. c_H and c_T are given by:

$$c_H = \frac{P}{P_0} \qquad (8)$$

2. The same equation is used to calculate wind speed at the 10-meter level, with H set to 10 m. This latter value has no bearing on the energy calculation procedure; it is calculated in order to provide a common basis to compare two sites for which the wind speed has been measured at different heights.

$$c_T = \frac{T_0}{T} \tag{9}$$

where P is the annual average atmospheric pressure at the site, P_0 is the standard atmospheric pressure of 101.3 kPa, T is the annual average absolute temperature at the site, and T_0 is the standard absolute temperature of 288.1 K.

2.3 Renewable Energy Delivered

The RETScreen Wind Energy Project Model calculates the renewable energy delivered to the electricity grid, taking into account various losses. In the special case of isolated-grid and off-grid applications, the amount of wind energy that can be absorbed by the grid or the load is also considered.

2.3.1 Renewable energy collected

Renewable energy collected is equal to the net amount of energy produced by the wind energy equipment:

$$E_C = E_G \ c_L \tag{10}$$

where E_G is the gross energy production, and c_L is the losses coefficient, given by:

$$c_L = (1-\lambda_a)\ (1-\lambda_{s\&i})\ (1-\lambda_d)\ (1-\lambda_m) \tag{11}$$

where λ_a is the array losses, $\lambda_{s\&i}$ is the airfoil soiling and icing losses, λ_d is the downtime losses, and λ_m is the miscellaneous losses. Coefficients λ_a, $\lambda_{s\&i}$, λ_d, and λ_m are specified by the user in the *Energy Model* worksheet.

2.3.2 Absorption rate and renewable energy delivered

The model calculates the wind energy delivered E_D according to:

$$E_D = E_C \; \mu \tag{12}$$

where E_C is the renewable energy collected (see equation 10), and μ is the wind energy absorption rate.

The wind energy absorption rate is the percentage of the wind energy collected that can be absorbed by the isolated-grid or the off-grid system. For central-grid applications, this rate is always equal to 100% since the grid is assumed to be large enough to always absorb all the energy produced by the wind energy project. For isolated-grid and off-grid applications, the user enters the value of the absorption rate.

For isolated-grid and off-grid applications, the model computes a *suggested wind energy absorption rate*. It is found by interpolation in ***Table 1***, where the Wind Penetration Level (WPL) is defined as:

$$WPL = \frac{WPC}{PL} \; 100 \tag{13}$$

where WPC is the wind plant capacity and PL is the peak load specified by the user. WPC is obtained by multiplying the number of wind turbines by their rated, or nameplate, capacity (power).

Average Wind Speed (m/s)	**Wind Penetration Level (WPL)**			
	0%	10%	20%	30%
0	100%	100%	100%	100%
4.9	100%	98%	96%	93%
5.6	100%	98%	94%	90%
6.3	100%	98%	93%	87%
6.9	100%	97%	92%	84%
8.3	100%	96%	90%	82%

Table 1: Suggested Wind Energy Absorption Rate for Isolated-Grid and Off-Grid Applications.

As illustrated in ***Table 1***, the suggested wind energy absorption rate varies according to the average wind speed and the wind penetration level. Note that it is based on the wind speed at the wind turbine hub height. ***Table 1*** values are derived from simulations conducted to establish the amount of wind energy delivered from windfarms installed in remote communities (i.e. isolated-grid and off-grid applications). The simulations considered combinations of wind regime, load profiles and equipment performance curves. Detailed results can be found in Rangi et al. (1992).

The model only provides suggested values for wind penetration levels less than 25%. However, if the wind penetration level is greater than 3% and the wind speed at hub height is 8.3 m/s or higher, then the model does not provide suggested values. Under these circumstances, the wind energy absorption rates will vary widely depending on the configuration of the system and on the control strategies adopted.

2.3.3 Excess renewable energy available

Excess renewable energy available E_X is simply the difference between the wind energy collected E_C and the wind energy delivered E_D:

$$E_X = E_C - E_D \tag{14}$$

2.3.4 Specific yield

The specific yield Y is obtained by dividing the renewable energy collected E_C by the swept area of the turbines:

$$Y = \frac{E_C}{N\ A} \tag{15}$$

where N is the number of turbines and A is the area swept by the rotor of a single wind turbine.

2.3.5 Wind plant capacity factor

The wind plant capacity factor PCF represents the ratio of the average power produced by the plant over a year to its rated power capacity. It is calculated as follows [Li and Priddy, 1985]:

$$PCF = \left(\frac{E_C}{WPC \; h_Y} \right) 100 \tag{16}$$

where E_C is the renewable energy collected, expressed in kWh, WPC is the wind plant capacity, expressed in kW, and h_Y is the number of hours in a year.

2.4 Validation

Numerous experts have contributed to the development, testing and validation of the RETScreen Wind Energy Project Model. They include wind energy modelling experts, cost engineering experts, greenhouse gas modelling specialists, financial analysis professionals, and ground station and satellite weather database scientists.

This section presents two examples of the validations completed. First, predictions of the RETScreen Wind Energy Project Model are compared to results from an hourly simulation program. Then, model predictions are compared to yearly data measured at a real wind energy project site.

2.4.1 Validation of wind energy model compared with an hourly model

In this section predictions of the RETScreen Wind Energy Project Model are compared with an hourly model. The hourly model used is HOMER, an optimisation model for designing stand-alone electric power systems (NREL, 2001). HOMER uses hourly simulations to optimise the design of hybrid power systems. HOMER can model any combination of wind turbines, photovoltaic panels, diesel generation, and battery storage. The present validation does not make use of the optimisation capabilities of HOMER; the program is used only as a simulation tool. Two configurations were tested: a small windfarm connected to an isolated-grid and a large windfarm connected to a central-grid.

Small windfarm

The system configuration used for the first test is based on a real wind power project in Kotzebue, Alaska, a small coastal community about 50 km North of the Arctic Circle (CADDET, 2001). The system comprises 10 turbines with a combined rated capacity of 500 kW; it is a joint undertaking between the US Department of Energy, the Electric Power Research Institute (EPRI), and the Alaska Energy Authority-Alaska Industrial Development Export Authority (AEA/AIDEA). The system services a small local grid, with a total population of 3,500. The system is designed to meet about 6% of the total electrical demand of the town. The system configuration is summarised in ***Table 2***.

Turbines	Atlantic Orient Corporation AOC 15/50
Number of turbines	10
Rotor diameter	15 m
Swept area	177 m^2
Hub height	24 m
Grid type	Isolated local grid
Local grid peak load	3.6 MW

Table 2: Kotzebue Wind System Configuration.

The power output curve of the AOC 15/50 is shown in ***Figure 9***. The same data were used for both software programs.

Weather data from the RETScreen online weather database for Kotzebue/Wien, AK, was used. RETScreen and HOMER differ in the type of wind speed they require. HOMER requires monthly wind speed values (shown in ***Table 3***) and stochastically estimates hourly values from these. RETScreen simply requires the annual average wind speed, which is equal to 5.8 m/s (all wind values are measured at 9.4 m). In both models, a Weibull wind distribution was used, with a shape factor of 2.0. The annual average atmospheric pressure is 101.1 kPa and the annual average temperature is -6°C.

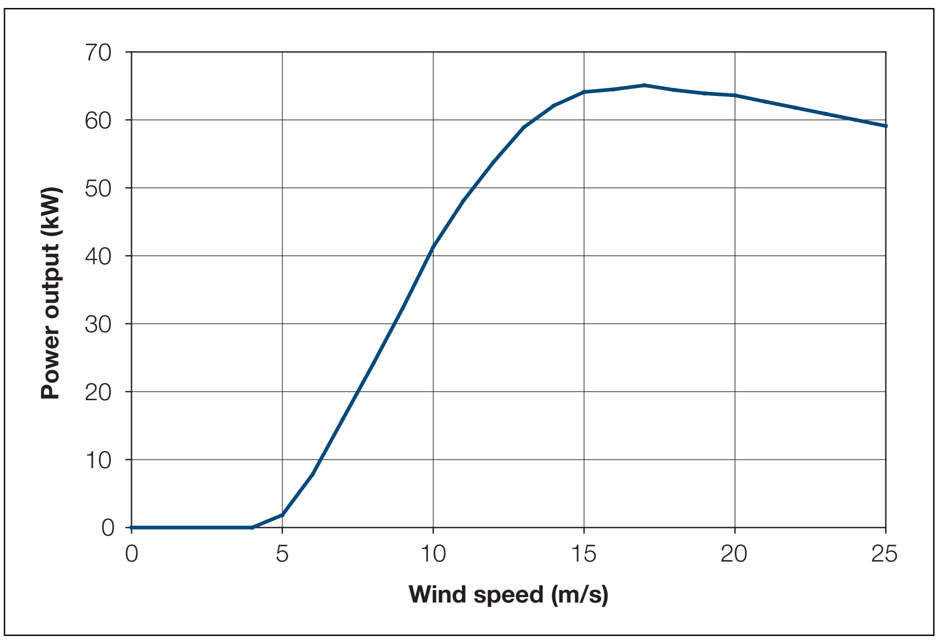

Figure 9:

AOC 15/50 Turbine Power Curve.

RETScreen requires a wind shear exponent to automatically calculate the wind speed at hub height. An exponent of 0.14 was used, which leads to a wind speed at hub height of 6.6 m/s. In HOMER a wind speed-scaling factor has to be entered manually. The factor used was set to 6.6/5.8 or 1.138 so that both RETScreen and HOMER use the same average wind speed at hub height.

Month	**Average Wind Speed** (m/s)
Jan	6.5
Feb	5.5
Mar	5.3
Apr	5.4
May	5.1
Jun	5.6
Jul	5.7
Aug	5.8
Sep	6.1
Oct	6.2
Nov	6.7
Dec	6.0
Yearly Average	**5.8**

Table 3:
Average Wind Speeds in Kotzebue, AK.

Comparison between HOMER and RETScreen requires exercising some judgement because the two programs do not necessarily require the same inputs, nor do they necessarily correct for the same physical phenomena. In many respects, RETScreen tends to be more thorough in its description of the system. For example RETScreen automatically calculates the pressure adjustment coefficient and the temperature adjustment coefficient. In HOMER, these values have to be manually entered in the form of a power curve-scaling factor. Similarly, RETScreen allows the user to specify array losses, losses due to airfoil soiling or icing, and downtime losses; these have no equivalent in HOMER. Finally RETScreen allows the user to specify a wind energy absorption rate; again there is no equivalent in HOMER. For these reasons, the comparison will be more meaningful if *unadjusted energy production* values calculated by RETScreen are used, rather than the *renewable energy delivered*.

Table 4 compares the annual energy productions predicted by RETScreen and HOMER. As can be seen, the agreement between the two software programs is excellent. *Section 2.4.2* will show that the agreement with experimental data is also acceptable in terms of actual renewable energy delivered, that is, once energy production is adjusted for various losses and pressure and temperature effects.

RETScreen Unadjusted Energy Production (MWh)	HOMER Total Energy Production (MWh)	Difference
1,532	1,515	**+1.12%**

Table 4: Comparison of Predicted Annual Energy Production – Small Windfarm.

Large windfarm

The second test configuration represents a large windfarm connected to a central-grid. The main parameters of the system are as follows:

- 76 Vestas V47-600kW turbines (hub height 55 m, diameter 47 m).
- Annual average wind speed: 8.1 m/s.
- Annual average temperature: 12°C.
- Altitude of site: 250 m, annual average atmospheric pressure: 98.4 kPa.
- Wind speed distribution: Weibull, shape factor: 1.8.
- Wind shear exponent: 0.14.

The power output curve of the Vestas V47-600kW turbine is shown in ***Figure 10***. The same data were used for both software programs.

According to RETScreen the average wind speed at hub height is 10.3 m/s. As in the small windfarm case, a wind speed-scaling factor equal to 10.3/8.1 or 1.272 had to be entered manually in HOMER so that both programs use the same average wind speed at hub height.

As before, *unadjusted energy production* values calculated by RETScreen are used, rather than the actual *renewable energy delivered*, to facilitate comparison with HOMER. The comparison is shown in ***Table 5***. Once again, the agreement between the two software programs is excellent.

RETScreen Unadjusted Energy Production (GWh)	HOMER Total Energy Production (GWh)	Difference
258.2	265.2	**-2.64%**

Table 5: Comparison of Predicted Annual Energy Production – Large Windfarm.

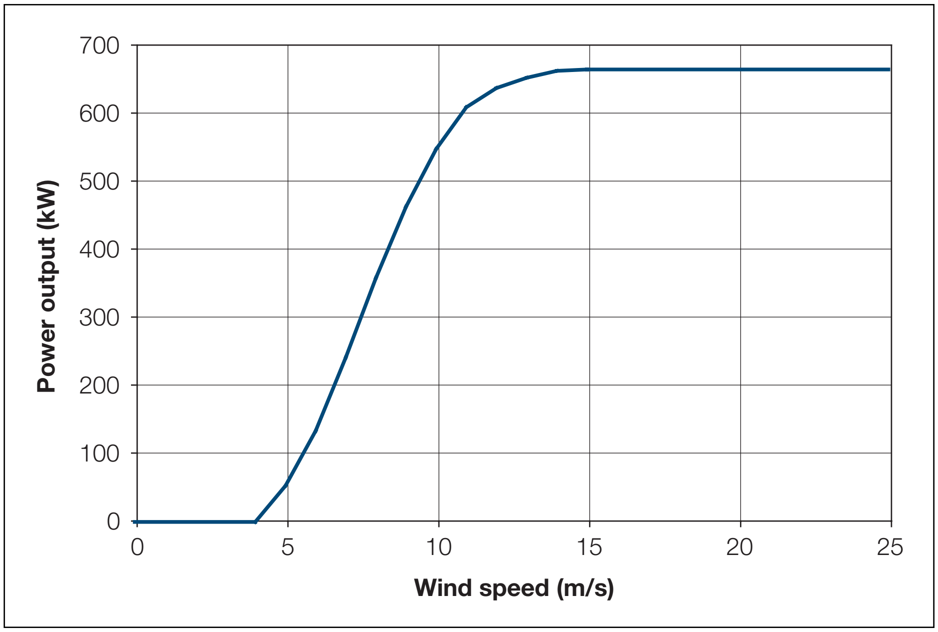

Figure 10:

Vestas V47-600kW Turbine Power Curve.

2.4.2 Validation of wind energy model compared with monitored data

Annual monitoring data have been published for the small windfarm system described in *Section 2.4.1.* This makes a brief experimental validation of RETScreen Wind Energy Project Model possible.

The system's 10 turbines were installed in several phases. Electricity production from turbines 1-3 is available for years 1998 and 1999; for turbines 4-10, one-year of electricity production is available from July 1999 to June 2000. Electricity production figures can be found in CADDET (2001). Bergey (2000) also reports on system performance for the 10 turbines. A caveat in using these data is that the first couple of years of production of a system can sometimes not be representative, as there are often "teething" problems and adjustments required. This is especially true for one-of-a-kind applications. One should keep this in mind when reading the following comparison.

Monitored wind speeds, as presented in ***Table 6***, were used as inputs to RETScreen. In the absence of additional information, the following conservative estimates were used: 95% wind energy absorption rate, 3% array losses, 5% airfoil soiling and/or icing losses, and 5% for miscellaneous losses. Downtime losses are difficult to estimate. According to CADDET (2001) the turbines were available 96% of the time; however that figure excludes many downtimes for scheduled maintenance and grid failures, which should be included in the value used by RETScreen. The "other downtime losses" parameter in RETScreen was therefore estimated at roughly 10%; this is probably still too low a value given the harsh conditions to which the system is subjected and the fact that the system is still in its "infancy."

Table 6 summarises RETScreen predictions versus actual energy production. RETScreen reasonably predicts the actual electricity production, except in 1999 where the energy production of the monitored project appears to have under-performed. For example, when comparing production of turbines 1-3 in 1998 and in 1999, it appears that the 3 turbines actually only produced 23% less energy in 1999 although the average wind was 10% higher than in 1998. Also, average production per turbine for a 5.4 m/s wind speed was 69.5 MWh in 1999 according to CADDET (2001) whereas it was 117.0 MWh (or 68% more) in 1999/2000 for the same 5.4 m/s average wind speed according to Bergey (2000). Again these discrepancies may be due to problems experienced by the installed wind energy system in its first few years of operation, and solved since then. The comparison of RETScreen predictions with real data is nevertheless acceptable and this, together with the model-to-model comparison of *Section 2.4.1*, confirms the adequacy of RETScreen for pre-feasibility studies of wind energy projects.

Period	**Turbines**	**Average Wind Speed** (m/s)	**RETScreen Prediction** (MWh)	**Actual Electricity Production** (MWh)	**Difference**
1998*	1-3	4.9	250	270.9	-8%
1999*	1-3	5.4	317	208.6	+52%
July 1999-June 2000*	4-10	5.1	646	546.9	+18%
1999-2000**	1-10	5.4	1,057	≈1,170	-10%

* From CADDET (2001). ** From Bergey (2000).

Table 6: Comparison of RETScreen Predictions against Monitored Data for Kotzebue, AK.

2.5 Summary

In this section the algorithms used by the RETScreen Wind Energy Project Model have been shown in detail. The model uses a user-specified power curve and a Weibull wind speed probability distribution function to calculate the energy curve of the turbine. Energy production is then adjusted for pressure and temperature effects, as well as for various user-specified losses. In the case of isolated-grid and off-grid applications, the calculation of wind energy delivered takes into account the wind energy absorption rate. Comparison of the RETScreen model predictions against results of an hourly simulation program and against monitored data shows that the accuracy of the RETScreen Wind Energy Project Model is excellent in regards to the preparation of pre-feasibility studies, particularly given the fact that RETScreen only requires 1 point of wind speed data versus 8,760 points of data for most hourly simulation models.

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