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# IMPROVING PERFORMANCE OF RENEWABLE GENERATING PLANTS : WELL-DEFINED AND WELL-MEASURED INDICATORS WILL MAKE THE TASK EASIER

Bruno MANOHA  
Electricité de France



# MEASURING THE PERFORMANCE OF A POWER PLANT IS OF MAJOR IMPORTANCE

- **WEC PGP Committee (Performance of Generating Plants) since 1974**
  - Compilation, Analysis and Publication of performance data worldwide
  - Nuclear and fossil-fired power plants in a first step
- **PGP has demonstrated the enormous value of plant availability:**

It has been estimated that improving the availability of all power plants in the world to the performance levels achieved today by the 25% best performing plants, is worth a staggering US\$ 80 billion per year. In addition, this improvement would reduce the annual global GHG emissions by 1 billion tonnes CO<sub>2</sub> (i.e. by approximately 4%) → use of best practices
- **WEC PGP tries now to extend the work to Renewable Energy**

# HOW DOES WEC PGP WORK ? WHAT DOES IT NEED ?

PGP Working Group  
(nuclear, fossil, ...)

Definition of  
Performance Indicators

*Clear and simple*

*Precise definitions*

Collection of measurements

*Clear standards*

Compilation in database

Analysis of best practices

Publication, communication, workshops

**Improvement of performances**

ISO,  
IEC,  
...



# MAIN OBJECTIVES OF WEC PGP WG3 « NEW RENEWABLES AND ENVIRONMENT » :

- **Promote efficient development of Renewable Energy**  
(Wind, solar PV, biomass and geothermal energies)
- **Improve the performance of generating plants utilizing them**

- **Phase 1** : *Proposal of Technical Indicators for RES*
- **Phase 2** : *Proposal of Environmental and Sociological indicators*
- **Phase 3** : *Consolidation and promotion of the results*  
*Next phase = databases ?*



The general aim of the work is that the proposed indicators can be useful to all experts, organisations and countries willing to develop renewable energy, in order to help compare and position various technologies, analyse and identify their eventual weaknesses, and thus improve their performances, and finally help a more efficient development of RES.

# SOME TECHNICAL PERFORMANCE INDICATORS PROPOSED IN PHASE 1

<b><u>Technical</u> Performance Indicator</b>	<b>Type of RES</b>	<b>Ease of measurement / estimate</b>	<b>Comparability from one site to another</b>
<b>Capacity Factor (%)</b>	Wind, Biomass, Geothermal	Easy	OK
<b>Load Factor (%)</b>	Geothermal	Easy	OK
<b>Specific Energy Production (kWh/m<sup>2</sup>)</b>	Wind	Easy	OK
<b>Equivalent Full Load Hours (hours)</b>	All	Easy	OK
<b>Availability Factor (%)</b>	Wind, Biomass, Geothermal	Easy	OK
<b>Reference Yield (hours/day)</b>	PV	Rather difficult	OK
<b>Array Yield (hours/day)</b>	PV	Rather difficult	OK
<b>Final Yield (hours/day)</b>	PV	Rather difficult	OK
<b>Performance Ratio (%)</b>	PV	Rather difficult	OK
<b>Efficiency (higher heat value)</b>	Biomass	Easy	More or less
<b>Fuel Moisture</b>	Biomass	Easy	More or less
<b>Annual energy sent out (MWh/year)</b>	Biomass	Easy	More or less

# SOME ENVIRONMENTAL AND SOCIOLOGICAL PERFORMANCE INDICATORS PROPOSED IN PHASE 2

<u>Environmental</u> Performance Indicator	Type of RES	Ease of measurement / estimate	Comparability from one site to another
Contribution to the reduction of greenhouse gases (t CO <sub>2</sub> /MW/year)	All	Rather difficult	OK
Pollutants emissions during the life cycle of the plant (g/kWh)	All	Rather difficult	OK
External (environmental) cost (%)	All	Difficult	More or less
Land area required for production of 1 GW (km <sup>2</sup> )	All	Easy	OK
Visual effects / Landscape protection distance (m)	Wind	Easy	OK
Sound from wind turbines (dB)	Wind	Easy	OK
Birds fatalities (nber/year)	Wind	Rather easy	OK
Shadow casting (hours/year)	Wind	Easy	OK
Quantities of toxic materials in PV cells and batteries (g/Wp)	PV	Rather difficult	OK
Specific pollutants emissions during the life cycle (g / kWh)	Biomass	Easy	OK
H <sub>2</sub> S emissions during the life cycle of the plant (g / kWh)	Geothermal	Easy	OK

<u>Sociological</u> Performance Indicator	Type of RES	Ease of measurement / estimate	Comparability from one site to another
Number of jobs created by the plant (n/MW)	All	Easy	OK
Number of people having now access to the electricity (n/MW)	All	Easy	OK
Industrial safety accident rate (n/1,000,000 man-hours worked)	All	Easy	OK

# Example of Plaquette for Wind Energy



## TECHNICAL PERFORMANCE INDICATORS FOR WIND ENERGY



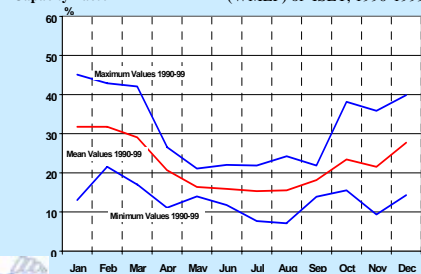
**Background :** The performance indicators proposed here are the results of the work of the WEC Committee on the Performances of Generating Plants (PGP). Their objective, through benchmarking, cross-comparisons, inter-comparisons, and eventually databases, is to help to compare the merits and demerits of various technologies, identify and analyse their eventual weaknesses, and thus lead to improvements in their performances and finally contribute to a more efficient and vigorous development of Renewable Energies.

Proposed Technical Indicators	Definitions and comments
<p><b>Capacity Factor (%) =</b>  <math display="block">\frac{\text{Total energy production during the nominal period}}{\text{Potential energy production during the period}}</math></p> <p><b>Specific energy production (kWh/m<sup>2</sup>) =</b>  <math display="block">\frac{\text{Total energy production during the nominal period}}{\text{Swept rotor area}}</math></p> <p><b>Equivalent full load hours (h) =</b>  <math display="block">\frac{\text{Annual energy production}}{\text{Rated power}}</math></p> <p><b>Availability Factor (%) =</b>  <math display="block">\frac{\text{Total hours of operation of plant during the period} \times 100}{\text{Total length of the period (hours)}}</math></p> <p><b>Wind conditions during the period (m/s) =</b>                      Average wind speed and wind speed distribution</p>	<ul style="list-style-type: none"> <li><b>Nominal period (hours)</b> = complete period covered by the report, usually one year</li> <li><b>Total energy production (kWh)</b> = energy delivered at the connecting point during the monitoring (nominal) period, usually one year</li> <li><b>Potential energy production (kWh)</b> = rated power x monitoring (nominal) period, usually one year</li> <li><b>Specific energy production (kWh)</b> is also often called «energy yield» or «energy productivity», and is very much dependant on the rated power of the turbines.</li> <li><b>Period of non availability (h)</b> = period during which the plant is not functioning. This can be scheduled (maintenance) or not (failure, malfunction). The availability usually ranges around 95% for wind farms.</li> <li><b>Wind conditions</b> are very important to be able to compare the performances of plants (see next page)</li> </ul>

**Remarks :**

- Other general information must of course be provided for further analysis and fair comparisons : plant size, cycle of operation, age, vintage, type of turbines, etc ...
- The notion of « availability - non availability » is a rather complex notion. One should refer to the **norm IEC 61400-25** for more details and standardization of the definitions.

**Sample Application :** The hereunder figure shows the **Monthly Capacity Factor** of the wind turbines studied in the German « Scientific Measurement and Evaluation Program » (WMEP) of ISET, 1990-1999.



The actual monthly energy delivery achieved by all observed plants is thereby related to the theoretically maximum total monthly production with continuous full load, whereby 125,000 monthly energy delivery reports from the years 1990-1998 were available. The average values of the individual months (and therefore the expectation values) range from 15% in July, to 32% in January. According to the general weather situation and the annual available wind, deviations can be noted which range from the mini-mum value in August 1997 with 7% capacity factor, to the maximum value of 45% in January 1993.

### Importance of the Wind conditions

The **Power Curve**  $P=f(v)$  (fig.1) is dependant on :

- the atmospheric conditions, i.e. wind speed, air pressure and turbulence
- the system design, i.e. rated power, rotor diameter and hub height

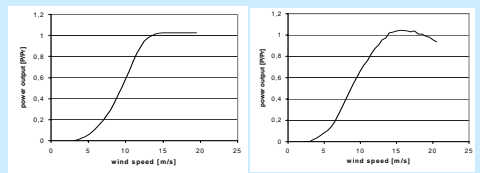


Fig.1 Measured power curve of turbine with pitch control and variable speed (a) and stall control and constant speed (b)

A very good knowledge of the **wind conditions** is of prime importance for an optimum prediction of the potential energy production. Wind measurements must be carried out and documented in terms of :

- mean wind speed (monthly, seasonal, annual)
- speed frequency and distribution (fig.2)
- directional distribution of wind energy (fig.3)
- monthly turbulence intensity (ratio between standard deviation and mean value)

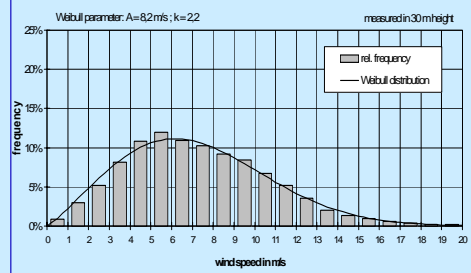


Fig.2 Wind speed - frequency and Weibull distribution

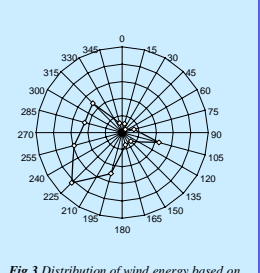


Fig.3 Distribution of wind energy based on energetically weighted frequency distribution of the wind direction in 12 sectors

This **Case Study from Germany** (fig.4) shows that the gross available wind energy can vary significantly from one year to another, depending on the wind conditions during the year.

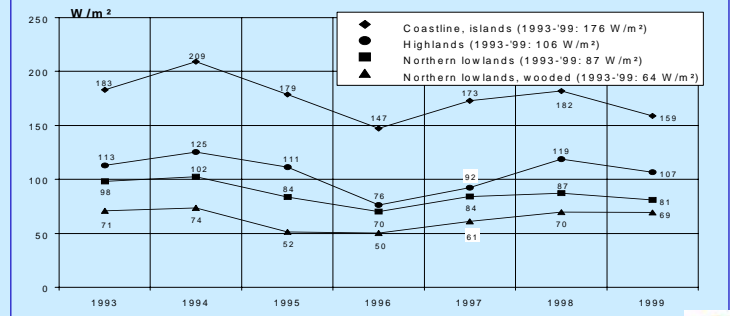


Fig.4 Gross wind energy supply by years



WEC Working Group on the Performances of Generating Plants (PGP)



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## ENVIRONMENTAL PERFORMANCE INDICATORS FOR WIND ENERGY



### Proposed Environmental Performance Indicators

#### General indicators

(also applicable to other types of power plants)

#### Contribution to the reduction of greenhouse gas emissions :

**AvCO<sub>2</sub> (t/MW/y)** = avoided CO<sub>2</sub> emissions (in metric tonnes per MW per year), compared to what would have been emitted by a new plant built in the region, given the same annual production (in kWh), using as fuel the most likely future fuel choice, or by the plant most likely to be displaced by the new RES facility (usually the oldest plant scheduled for retirement)

#### Pollutant emissions during the life cycle (g / kWh) :

**Q<sub>CO<sub>2</sub></sub>, Q<sub>SO<sub>x</sub></sub>, Q<sub>NO<sub>x</sub></sub> (g/kWh)** = quantities of CO<sub>2</sub>, SO<sub>x</sub> and NO<sub>x</sub> emitted per kWh during the whole life cycle of the plant

#### Specific indicators

#### Visual effects / Landscape protection distance (m) :

**d<sub>min</sub> (m)** = Minimum distance away from nearby dwellings

#### Noise from wind turbines (dB) :

**S<sub>f</sub>** = Maximum noise (dB) at the foot of the wind turbines

**S<sub>500</sub>** = Maximum noise (dB) 500 m away from the wind turbines

**S<sub>st</sub>** = Maximum noise (dB) at standard distance H + D/2 according to norm IEC 61400-11

#### Birds fatalities (n/y) :

**Nb** = Number of birds killed per wind turbine per year

#### Shadow casting (h/y) :

**Nsc** = Number of hours per year when the proximate dwellings suffer of shadow casting from the wind turbines

### Samples and comments

\* Total European wind farms (16300 MW) avoid 30 million tons CO<sub>2</sub> / year (source ADEME France)

\* WindPower Denmark : avoided CO<sub>2</sub> = 2000 t/MW/year

\* US AWEA : 750 kW wind turbine avoids 1500 t CO<sub>2</sub> / year

**Comment** : the reference technology displaced must be quoted (coal, oil, gas).

$$Q_{CO_2} = 7 - 9 \text{ g / kWh}$$

$$Q_{SO_x} = 0.02 - 0.09 \text{ g / kWh}$$

$$Q_{NO_x} = 0.02 - 0.06 \text{ g / kWh}$$

( Source IEA, Benign Energy ?,  
The Environmental Implication of  
Renewables, OECD Paris, 1998 )

France recommends a minimum distance of 500 m

- EDF recommends S<sub>500</sub> lower than 35 dB

- Nordex 2.5 MW = 102.8 dB(A) at hub for a 8m/s wind

- For most turbines, S<sub>f</sub> < 55 dB

- WT 2 MW : S<sub>500</sub> = 39.7 dB  
and S<sub>250</sub> = 48.2 dB (source  
Systèmes Solaires)

Nb = 0.4 to 1.3 average Europe

Nb = 5.2 average California

France : maximum 5 to 12 hours per year (source ADEME)

## SOCIOLOGICAL PERFORMANCE INDICATORS FOR WIND ENERGY



### Proposed Sociological Indicators

#### - Jobs created by the plant (n/MW) :

**N<sub>j</sub>** = number of jobs (direct / indirect) created by a 1 MW power plant for the different steps : manufacture, installation, operation and maintenance.

#### - Providing access to electricity :

**N<sub>a</sub>** = number of households / total number of people having now access to the electricity produced by a 1 MW plant, and who would not have such access if another type of plant were to be built (grid connected).

#### - Industrial Safety Accident Rate :

**SAR** = number of accidents for all utility personnel permanently assigned to the plant (contractor personnel not included), that result in one or more days away from work (excluding the day of the accident) or one or more days of restricted work (excluding the day of the accident), or fatalities, per 1,000,000 man-hours worked.

#### For more information, please contact :

- \* World Energy Council (WEC) at <http://www.worldenergy.org>  
5th Floor, Regency House, 1-4 Warwick Street, London W1R 6LE, UK.  
Tel: (+44 20) 7734 5996 Fax: (+44 20) 7734 5926 E-mail: [info@worldenergy.org](mailto:info@worldenergy.org)
- \* Institut für Solare Energieversorgungstechnik at <http://www.iset.uni-kassel.de>  
Königstor 59, D-34119 Kassel, Germany  
Tel : +49 (0) 561 7294-0 Fax : +49 (0) 561 7294-100 E-mail : [mbox@iset.uni-kassel.de](mailto:mbox@iset.uni-kassel.de)
- \* or Bruno Manoha, Chairman of the WEC WG on the Performances of Renewable Energies,  
at [bruno.manoha@edf.fr](mailto:bruno.manoha@edf.fr)

### Samples and comments

- Beware of **subsidies** in some countries which can distort the data and prevent meaningful comparisons.
- A **distinction** must be made between job-years for **manufacturing** and **installation** on one hand, and jobs for **O&M** on the other hand, especially when the manufacturer is not in the country of installation.
- A European study of 1999 assumes that 17 job-years of employment are created for every MW of wind energy capacity manufactured, and a further 5 job - years for the installation of every MW, bringing the total to 22 job - years.
- The latest update of *Wind Force 12* (EWEA, 2003a) suggests that the feasible number of jobs created in the wind industry worldwide by 2020 will be 1.8 million.

**Recall** : we have chosen in the study to focus only on grid-connected plants. In developing countries, isolated wind turbines may bring power to people who may not, otherwise, have access to electricity at all without them.

- WindPower Denmark : 1 MW wind energy provides electricity to 500 to 800 households in Europe.
- Edens Italy : a wind plant rated 1 MW can provide electricity for 1000 houses (without heating)

- This indicator is already widely used for other conventional types of power plants (nuclear, fossil-fired, etc...).
- The purpose of this indicator is to monitor progress in improving industrial safety performance for all utility personnel permanently assigned to the utility's staff.
- This indicator was chosen as the personnel safety indicator over other indicators, such as injury rate or severity rate, because the criteria are clearly defined, utilities currently collect this data, and the data are the least subjective.

# WHAT NEXT ?

The question is : can we do for Renewable Energy what has been done for nuclear and fossil-fired power plants ? Maybe difficult, but at least two first steps will be necessary if we want to go further :

→ **Data-bases** : going further means collection of performance data in data-bases. Rather than trying to set up new specific WEC PGP data-bases, the idea would be to privilege collaborations with already existing performance databases.

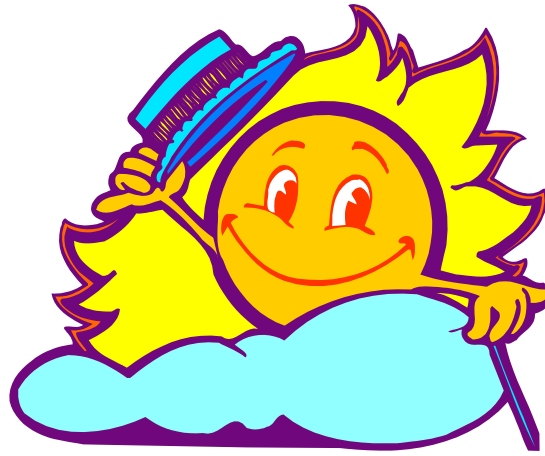
Examples:

- *for wind* → WindStats data-base exists since many years (mostly European)  
→ NERC GADS data-base is under preparation (cf. Mike Curley within WEC PGP - mostly focused on North American wind farms)
- *for PV* → IEA PVPS data-base is developed since 2000

→ **Definitions**: we will then have, with the above partners, to complement and more precisely detail some of the proposed definitions of the indicators, with the additional help and implication of international organisations. IEC/ISO for example could participate (cf. norms IEC 61400 for wind, IEC 60904 for PV).

**WEC PGP is thinking about it**

**Report on indicators available on WEC web site [www.worldenergy.org](http://www.worldenergy.org) :  
« Performance of Generation Plants : New Realities, New Needs » - August 2004**



**Thank You**