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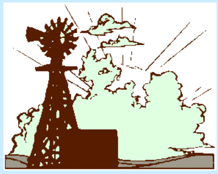
TECHNICAL PERFORMANCE INDICATORS FOR WIND ENERGY



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

Capacity Factor *(%)* =

$$\frac{\text{Total energy production during the nominal period}}{\text{Potential energy production during the period}}$$

Specific energy production *(kWh/m²)* =

$$\frac{\text{Total energy production during the nominal period}}{\text{Swept rotor area}}$$

Equivalent full load hours *(h)* =

$$\frac{\text{Annual energy production}}{\text{Rated power}}$$

Availability Factor *(%)* =

$$\frac{\text{Total hours of operation of plant during the period x 100}}{\text{Total length of the period (hours)}}$$

Wind conditions during the period (m/s) =
Average wind speed and wind speed distribution

Definitions and comments

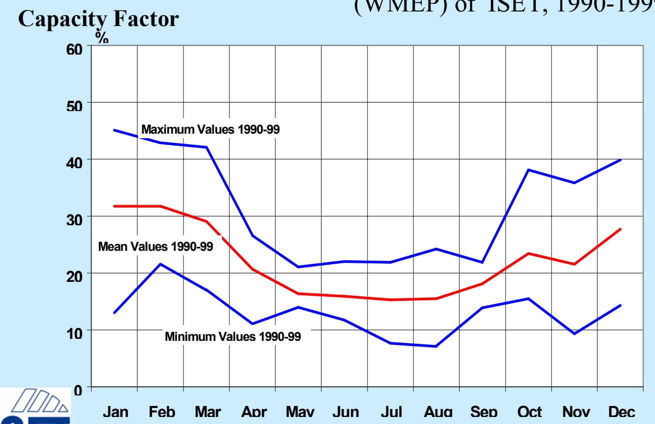
- **Nominal period *(hours)*** = complete period covered by the report, usually one year
- **Total energy production *(kWh)*** = energy delivered at the connecting point during the monitoring (nominal) period, usually one year
- **Potential energy production *(kWh)*** = rated power x monitoring (nominal) period, usually one year
- **Specific energy production *(kWh)*** is also often called «**energy yield**» or «**energy productivity**», and is very much dependant on the rated power of the turbines.
- **Period of non availability *(h)*** = period during which the plant is not functionning. This can be scheduled (maintenance) or not (failure, malfunction). The availability usually ranges around 95% for wind farms.
- **Wind conditions** are very important to be able to compare the performances of plants (see next page)

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 … Life time and return time (number of years of production of electricity needed for implementation of the plant) should also be provided when available.
- 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.
- **Complementary indicator** to be used when possible = % predicted versus really produced electricity (24h, 48 h, 1 week in advance)

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.

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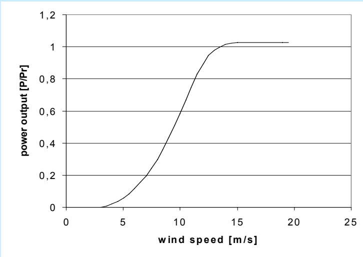
Importance of the Wind conditions

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



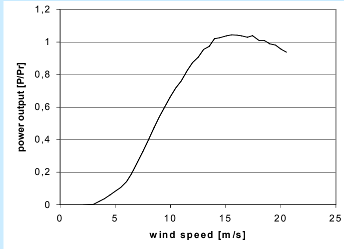


Fig.1 *Measured power curve of turbine with pitch control and variable speed (a) and stall control and constant speed (b)*

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*)
- directionnal distribution of wind energy (*fig.3*)
- monthly turbulence intensity (ratio between standard deviation and mean value)

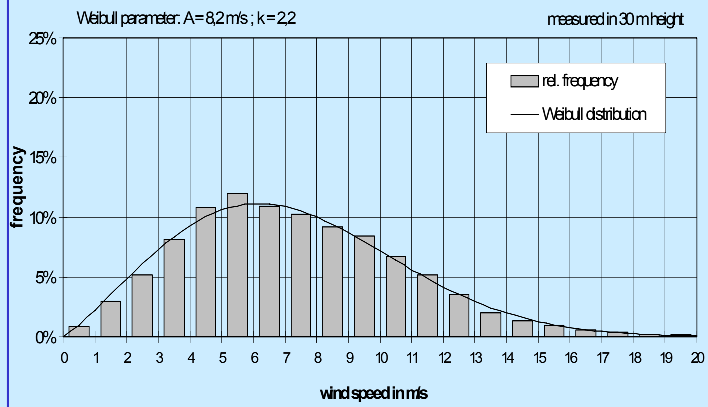


Fig.2 *Wind speed - frequency and Weibull distribution*

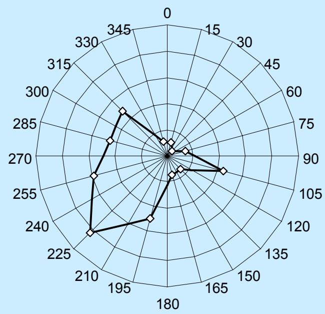


Fig.3 *Distribution of wind energy based on energetically weighted frequency distribution of the wind direction in 12 sectors*

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

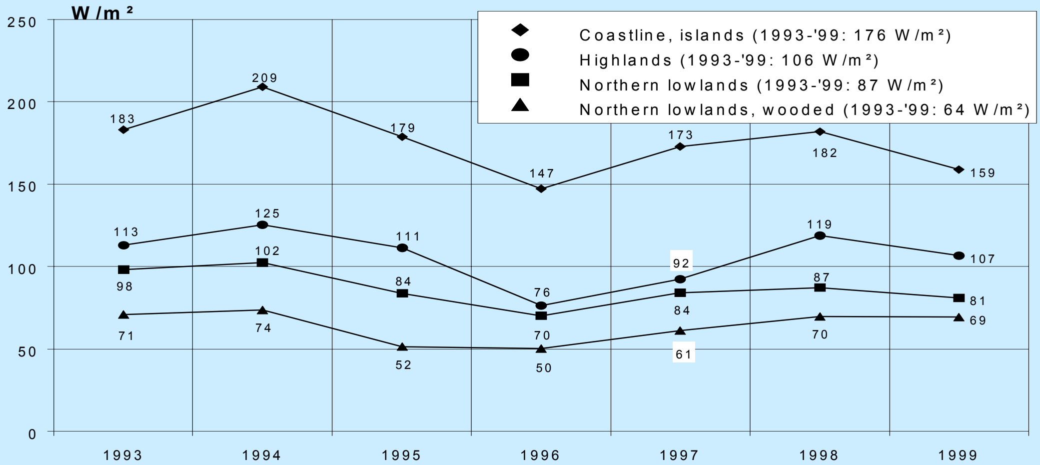


Fig.4 *Gross wind energy supply by years*

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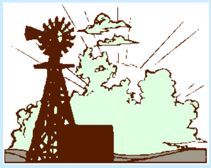

Proposed Environmental Performance Indicators | Samples and comments

General indicators
(also applicable to other types of power plants)

Contribution to the reduction of greenhouse gas emissions :

AvCO2 (t/MW/y) = avoided CO2 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)

Samples and comments:

* Total European wind farms (16300 MW) avoid 30 million tons CO_2 / year (source ADEME France)

* WindPower Denmark : avoided CO_2 = 2000 t /MW/year

* US AWEA : 750 kW wind turbine avoids 1500 t CO_2 / year

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

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

Q_{CO2}, Q_{SOx}, Q_{NOx} **(g/kWh)** = quantities of CO2, SOx and NOx emitted per kWh during the whole life cycle of the plant

Samples and comments:

Q_{CO2} = 7 - 9 g / kWh

Q_{SOx} = 0.02 – 0.09 g / kWh

Q_{NOx} = 0.02 – 0.06 g / kWh

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

Specific indicators

Visual effects / Landscape protection distance (m) :

d_{min} **(m)** = Minimum distance away from nearby dwellings

Samples and comments: France recommends a minimum distance of 500 m

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Noise from wind turbines (dB) :

S_f = Maximum noise (dB) at the foot of the wind turbines

S_{500} = Maximum noise (dB) 500 m away from the wind turbines

S_{st} = Maximum noise (dB) at standard distance H + D/2 according to norm IEC 61400-11

Samples and comments:

- EDF recommends S_{500} lower than 35 dB
- Nordex 2.5 MW = 102.8 dB(A) at hub for a 8m/s wind
- For most turbines, S_f < 55 dB
- WT 2 MW : S_{500} = 39.7 dB and S_{250} = 48.2 dB (source Systèmes Solaires)

Birds fatalities (n/y) :

Nb = Number of birds killed per wind turbine per year

Samples and comments:

Nb = 0.4 to 1.3 average Europe

Nb = 5.2 average California

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

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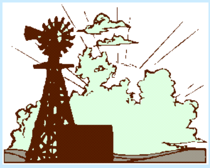
SOCIOLOGICAL PERFORMANCE INDICATORS FOR WIND ENERGY



Proposed Sociological Indicators	Samples and comments
- **Jobs created by the plant (n/MW) :** **Nj** = number of jobs (direct / indirect) created by a 1 MW power plant for the different steps : manufacture, installation, operation and maintenance.	• 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.
- **Providing access to electricity :** **Na** = 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).	***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)
- **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.	• 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.

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TECHNICAL

PERFORMANCE INDICATORS FOR

PHOTOVOLTAIC 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.

Technical Performance Indicators	Definitions
Reference Yield, Y_R $$Y_R = \frac{E_{S,A} \ [kWh/(m^2 \cdot d)]}{G_{STC} \ [kW/m^2]}$$	The **Reference yield** Y_R is the daily (monthly or annual) in-plane irradiation $E_{S,A}$ divided by the STC reference in-plane irradiance G_{STC} (= 1 kW/m²) It has the dimension *h/d* and can be considered as the number of hours per day during which the solar radiation would be at reference irradiance level, in order to contribute the same energy incident as was monitored.
Array Yield, Y_A $$Y_A = \frac{E_{A,d} \ [kWh/d]}{P_o \ [kWp]}$$	The **Array yield** Y_A is the daily (monthly or annual) array energy output $E_{A,d}$ per kWp of installed PV array power *Po* It has the dimension *kWh/(d · kWp)* and can be considered as the number of hours of array operation per day at *Po*, which would give the same energy output as the recorded integral value for that day (month or year).
Final Yield, Y_F $$Y_f = \frac{E_{use} \ [kWh/d]}{P_o \ [kWp]}$$	The **Final yield** Y_f is the daily (monthly or annual) plant useful energy output E_{use} per kWp of installed PV array power *Po*: It has the dimension *kWh/(d · kWp)* and can also be considered as the number of hours of plant operation per day at *Po*, which would give the same energy output as the recorded integral value for that day (month or year).
Performance Ratio, PR $$PR = \frac{Y_f}{Y_R}$$	The **Performance Ratio**, *PR* indicates the overall effect of losses on array's rated output due to array temperature, incomplete utilisation of the irradiation, and system component inefficiencies or failures.

Remark:

PV systems of different configurations and at different locations can be readily compared, by evaluating suitable normalised system performance indicators. The proposed indicators are already commonly used by PV system operators and are stated by different organisations (see: IEC 61742 *Photovoltaic system performance monitoring: Guidelines for measurement, data exchange and analysis*, 1998; IEA PVPS Task II *Operational performance of PV power systems: Measurements and monitoring approaches*, 1998).

Sample Applications

The following examples show data collected from some typical power plants :

In Italy :

Serre PV Central Station (3.3 MWp)

Year	1995	1996	1997	1998	1999
Reference Yield, Y_R [kWh/m²]	1674	1641	1784	1704	1723
[h/d]	4.58	4.50	4.89	4.67	4.72
Performance Ratio, PR [%]	48.0	70.4	68.7	68.7	68.6

Bovisa PV roof top plant (3 kWp)

Year	1999
Reference Yield, Y_R [h/d]	3.75
Final Yield, Y_f [h/d]	2.44
Performance Ratio, PR [%]	65.0

CESI PV roof top plant (3 kWp)

Year	1999
Reference Yield, Y_R [h/d]	3.32
Final Yield, Y_f [h/d]	2.35
Performance Ratio, PR [%]	70.9

Cagliari PV roof top plant (3 kWp)

Year	1999
Reference Yield, Y_R [h/d]	4.03
Final Yield, Y_f [h/d]	3.15
Performance Ratio, PR [%]	78.2

In Egypt : **experimental unit of 0.11 kWp PV water pumping station**

Year	July 1996
Reference yield Y_R [h/d]	4.36
Array Yield Y_A [h/d]	3
Final Yield Y_f [h/d]	1.086
Performance Ratio PR [%]	25%

In Japan : **Saijyo project 1000 kWp**

Year	2000
Reference yield Y_R [h/d]	3.84
Array Yield Y_A [h/d]	3.56
Final Yield Y_f [h/d]	3.32
Performance Ratio PR [%]	86%

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PERFORMANCE INDICATORS FOR

PHOTOVOLTAIC ENERGY

Proposed Environmental Performance Indicators	Samples and comments

General indicators
(also applicable to other types of power plants)

Contribution to the reduction of greenhouse gas emissions

AvCO2 (t/MW/y) = avoided CO2 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).

This indicator must take into account CO2 content of electricity used for manufacture of cells (manufacture nearly needs as much energy as will be produced during 2 to 3 years – lifetime of a cell = 20 to 25 years). The amount of CO2 will depend on the fuel mix of the country where the PV cells are manufactured.

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

Q_{CO2}, Q_{SOx}, Q_{NOx} (g/kWh) = quantities of CO2, SOx and NOx emitted per kWh during the whole life cycle of the plant

Q_{CO2} = 98 - 167 g / kWh

Q_{SOx} = 0.2 – 0.34 g / kWh

Q_{NOx} = 0.18 – 0.30 g / kWh

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

Specific indicators

Qtox (g/Wp) =
Quantities of toxic materials contained in the cells and batteries, that will have to be recycled or disposed of after the lifetime of the cells and batteries (Cd, etc …)

The duration of operation to produce the energy consumed for the manufacturing of the PV modules could be an additional indicator.

However, on one hand the PV cells are very often not used in the country where they have been manufactured, and on the other hand the operation of the PV plant can be very different from one place to another, and therefore very difficult to compare.

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SOCIOLOGICAL

PERFORMANCE INDICATORS FOR

PHOTOVOLTAIC ENERGY

Proposed Sociological Indicators	Samples and comments
- **Jobs created by the plant (n/MW) :** **Nj** = number of jobs (direct / indirect) created by a 1 MW power plant for the different steps: manufacture, installation, operation and maintenance.	• 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. • Estimate by CEA-France 2003 : 20 jobs per produced MW, 30 jobs per consumed MW • SEIA (Solar Energy Industry Association – USA) → 3,800 jobs created for every $ 100 million of PV cell sales.
- **Providing access to electricity :** **Na** = 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).	***Recall*** : we have chosen in the study to focus only on grid-connected plants. In developing countries, isolated PV modules may bring power to people who may not, otherwise, have access to electricity at all without them
- **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.	• 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.

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

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TECHNICAL PERFORMANCE INDICATORS FOR BIOMASS 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.

After hydroelectricity, biomass is the second biggest source of renewable energy. It utilises wood waste, agricultural and logging residue, animal dung, biogas, industrial and municipal waste. Direct biomass combustion technology is in fact very similar to coal combustion technologies, and the performance indicators proposed here are then rather similar to those developed for fossil-fired power plants.

Proposed Technical Performance Indicators

Efficiency (Higher Heat Value HHV) =

$$\frac{\text{Net output in heat unit}}{\text{Fuel heat input}}$$

Fuel moisture =

$$\frac{\text{Moisture (H2O)}}{\text{Total weight of fuel}}$$

Capacity Factor (%) =

$$\frac{\text{Total net electricity generation during the period (MWh) x 100}}{\text{Plant size (net MW) x Total length of period (hours)}}$$

Availability Factor (%) =

$$\frac{\text{Total hours of operation of plant during the period x 100}}{\text{Total length of period (hours)}}$$

Hours per year equivalent of the capacity factor =
Number of hours that would give the net annual generation if all operations were at full power of plant

Comments

- **Efficiency** = Net output in heat unit equivalent of the electricity, divided by the fuel heat input using the higher heating value of the fuel
- **Fuel moisture** = Moisture (H2O) as a fraction of the total (wet, not dry basis) weight of fuel
- **Capacity Factor** = Capability Factor used for «classical» fossil-fired power plants

Other general information must of course be provided for further analysis and fair comparisons : plant size, cycle of operation, age, vintage, etc … Life time and return time (number of years of production of electricity needed for implementation of the plant) should also be provided when available.

Definitions and typical (US) values

The following table recalls the performance indicators proposed for biomass energy, with their definitions and examples of typical values obtained in the USA, from 68 US power plants giving typical, low and high values of these indicators. These plants range up to 55 MW producing steam, electricity or both in cogeneration, and use either virgin wood, agricultural, animal, urban or other wood wastes.

Technical Indicator	Units	Definition	Typical Value	Low Value	High Value
Size [1]	MWe	Plant size in net power output	25	8	65
Generation	GWh/ year	Total electricity (net) generation per year	153.3	35.04	455.52
Capacity factor (annual) [2]		Total net electricity generation per year divided by plant size in net MW times the 8760 hrs in a year	0.700	0.500	0.800
Hours per year equivalent of the capacity factor (if run at full power) [3]	hours	Number of hours that would give the net annual generation if all operation were at full net size of plant	6132	4380	7008
Efficiency (higher heat value)		Net output in heat unit equivalent of the electricity divided by the fuel heat input using the higher heating value of the fuel	0.201	0.155	0.263
Heat Rate (SI units)	MJ/kWh	Fuel heat input per net electricity output	18	13.5	23
HHV Higher heating value (at moisture & ash free) [4]	MJ/kg	Heat content (HHV basis) if there were no moisture and no ash	19.7	18.6	20.9
Fuel ash content on dry basis	%	Fraction of the total fuel input by weight (dry, not as-received, basis) that is ash	2%	1%	10%
Dry Higher heating value (at ash given, but no moisture)	MJ/kg	Heat content (HHV basis) if there were no moisture, at ash given	19.3 (2% ash)	17.7 (10% ash)	19.5 (1% ash)
Fuel moisture [5]	%	Moisture (H2O) as a fraction of the total weight of fuel (wet, not dry basis)	30%	10%	60%
Wet Higher heating value (at moisture given, typical 2% ash)	MJ/kg	HHV at typical 2% ash content, at moisture given	13.5 (30% moisture)	7.7 (60% moisture)	17.3 (10% moisture)

Remarks :

(1) ***Size*** : in general, biomass plants tend to be small rather than large. They can be as low as a few hundred kWe, but the more realistic ranges from a few MW to 25 or 40 MW. 65 MW is rather large.
(2) ***Capacity factor***: this can reach 90%.
(3) ***Hours per year equivalent of the capacity factor** (if run at full power)**:*** it can reach 7800 hours/year.
(4) ***LHV (Lower Heating Value, or lower calorific value)*** is also used, especially in gasification. Usually LHV is 94% of HHV for biomass, so efficiency on LHV basis is 6% higher than on HHV basis.
(5) ***Fuel moisture***: general typical values range from 5-10% to 50%. Anything over 50% moisture creates too many problems. Bagasse for example has traditionally been used at 50% moisture content.

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ENVIRONMENTAL PERFORMANCE INDICATORS FOR BIOMASS ENERGY

Proposed Environmental Performance Indicators	**Samples and comments**

General indicators
(also applicable to other types of power plants)

Contribution to the reduction of greenhouse gas emissions

AvCO2 (t/MW/y) = avoided CO2 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).

When managed in a sustainable cycle (energy crops, replanting harvested areas, etc…), biopower generation can be viewed as a way to recycle carbon, and can be considered a carbon – neutral power generation option.

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

Q_{CO2}, Q_{SOx}, Q_{NOx} (g/kWh) = quantities of CO2, SOx and NOx emitted per kWh during the whole life cycle of the plant

For energy crops (current practice) :

Q_{CO2} = 17 - 27 g / kWh

Q_{SOx} = 0.07 – 0.16 g / kWh

Q_{NOx} = 1.1 – 2.5 g / kWh

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

Specific indicators

Q_{ash} (g/kWh) = Quantities of ash emitted, with their composition (Se, Pb, As, B …?) → cf. in particular agricultural residues, wood wastes, animal wastes, energy crops.

Q_{CH4} (g/kWh) = Quantities of **CH4** emitted from landfills (decomposition of biomass material) or decomposing animal manure (land-applied or left uncovered in a lagoon)

Biomass is a large and complex subject. Impacts on many natural features need to be carefully examined case by case; it is difficult to establish a few general criteria. For example, wood-processing wastes could be different from lumberyards' waste, agricultural waste, forest detritus, or energy farm trees. Impacts could be different in wetlands, desert or arid areas, forest lands, prairies, etc. The type of biomass and conditions of use must then be described carefully if we want to make useful comparisons

Additionnal possible indicator: the average distance of transportation of fuel (wood, …) to the plant can also be an interesting indicator, in terms of additional pollutants emitted during the transportation.

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SOCIOLOGICAL PERFORMANCE INDICATORS FOR BIOMASS ENERGY

Proposed Sociological Indicators	Samples and comments
- **Jobs created by the plant (n/MW) :** **Nj** = number of jobs (direct / indirect) created by a 1 MW power plant for the different steps: manufacture, installation, operation and maintenance.	• In France, the estimate is 4,5 direct jobs created for 1,000 tep (tonnes equivalent petroleum) produced or distributed , which means about 2 jobs / MW . • In the USA, EPRI gives an average value of about 20 full-time operating and supervising staff members for a 20 MW biomass power plant. Altogether (including operation, maintenance, truck drivers, etc …), a total of 1.6 jobs per MW is estimated by EPRI in the USA.
- **Providing access to electricity :** **Na** = 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).	***Recall*** : we have chosen in the study to focus only on grid-connected plants. In developing countries, biomass may bring power to people who may not, otherwise, have access to electricity at all without it.
- **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.	• 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.

For more information, please contact :

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* Electric Power Research Institute (EPRI) at *http://www.epri.com*
3412 Hillview Avenue, Palo Alto, CA 94304-1395, USA Tel: (1)650 855 2800 Fax : (1) 650 855 2800

* or Bruno Manoha, Chairman of the WEC WG on the Performances of Renewable Energies, at *bruno.manoha@edf.fr*

World Energy Council
CONSEIL MONDIAL DE L'ENERGIE

TECHNICAL PERFORMANCE INDICATORS FOR GEOTHERMAL 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 Performance Indicators

Capacity Factor =

$$\frac{\text{Total MWh generated in period x 100}}{\text{Installed Capacity (Mwe) x period (hours)}}$$

Load Factor =

$$\frac{\text{Total MWh generated in period x 100}}{\text{Maximum Load (Mwe) x period (hours)}}$$

Availability Factor =

$$\frac{\text{Total hours of operation of plant during the period x 100}}{\text{Total Length of period (hours)}}$$

Comments

• Both **Capacity and Load Factors** are needed to describe the technical performance of the plant. Where they are approximately the same, this is an indication that the installed capacity is equal to both the field conditions and the market conditions. On the other hand, where the Capacity Factor is significantly lower than the Load Factor, this is a sign that the installed capacity is too large either for the geothermal field or the market.

•The **unavailability** (%) of the plant (100-availability factor) is split into two categories :

Planned outage - An outage scheduled well in advance (at least two weeks) of the actual outage.

Forced outage - Unplanned outage that requires the plant to be taken out of service immediately or before the next planned outage.

Remarks :

Due to the importance of highlighting the effects of Planned/Forced Outages, two separate Availability Factors must be determined, including or excluding the time lost during the Planned Outage with respect to the actual operating hours.

Steam Availability Factor =

$$\frac{\text{Average steam flow (t/h) during period x 100}}{\text{Steam Supply (t/h)}}$$

An alternative definition of Steam Availability Factor could derive from the following consideration: some generation may be lost due to a shortfall in steam supplied from the steam-field; measuring the steam supply at the turbine inlet (t/h), thus:

Steam Availability Factor =

$$\frac{\text{[(Steam Supply)-(Steam Production Shortfall)]x100}}{\text{Steam Supply (t/h)}}$$

Sample Applications

The following examples show data collected from some typical power plants :

Year	1999
Installed Capacity	60 MW
Maximum Load	55 MW
Annual Produced Electricity	462845 MWh
Hours of Operation	8748 hrs
Capacity Factor	**88.1 %**
Load Factor	**96.1 %**
Availability Factor	**99.9 %**

Italian Plant n° 1 (60 MW)

Year	1999
Installed Capacity	20 MW
Maximum Load	17 MW
Annual Produced Electricity	142248 MWh
Hours of Operation	8443 hrs
Capacity Factor	**81.2 %**
Load Factor	**95.5 %**
Availability Factor	**96.8 %**

Italian Plant n° 2 (20 MW)

Year	1/4/97 - 31/3/98
Installed Capacity	50 MW
Maximum Load	48.3 MW
Annual Produced Electricity	361651 MWh
Hours of Operation	8112 hrs
Capacity Factor	**82.6 %**
Load Factor	**85.5 %**
Availability Factor	**92.6 %**

Japanese Plant (50 MW)

IGA

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

EDF

Definitions of specific terms

- **Geothermal Power Facility**

The main components of a Geothermal Power Facility are:
a) a number of wells to tap terrestrial heat from underground by means of a carrier fluid (steam, and/or hot water, and/or hot brine);
b) a gathering system of such fluid;
c) a power plant to use the heat of the carrier fluid for electricity production;
d) a condensed water, or residual water, or separated brine re-injection system.
The actual net electrical output of the plant results from interactions among these components.
In general, we have:

[geothermal power facility] = [production area] + [power plant]

- **Production Area**

In general, the Production Area of a geothermal field with conditions favourable for the generation of electric energy is usually formed by:
i. a group of production and reinjection wells;
ii. a steam/water, or steam/brine separation plant;
iii. a steam, or steam/water, or steam/brine gathering system;
iv. a steam condensate, or residual water, or separated brine reinjection system;
v. a steam venting system to cope with emergency situations;
vi. the control equipment associated with each of these components, which is needed to operate the Production Area in appropriate and safe conditions.

A Production Area is complete when it is capable of yielding the carrier fluid in the quantities and of the quality required to supply the associated Power Plant at its maximum output. All waste fluids are either reinjected into the underground for re-heating by terrestrial heat flow and steam regeneration or disposed in an environmentally sound manner.

- **Power Plant**

The Power Plant consists of single or multiple generating units including: steam or binary turbine, generator, condenser, cooling system, generator transformer, gas extraction system and all associated electrical control equipment. It is connected to the geothermal steam/brine supply system.

- **Installed Capacity**

The Installed Capacity (in MW_e) is the reference value for the power plant, set by the manufacturer as its target output, when the plant is operating at its design conditions.
Possible reserve units should not be considered as part of the installed capacity, but can be accounted for in a separate list.

- **Maximum Load**

The Maximum Load (in MW_e) is the highest average value over one hour from the power plant as measured at the generator transformer supply voltage terminals, when operating at its stated design conditions or adjusted to point conditions. It can also be denominated as «Running Capacity» or «Maximum Net Deliverable Capacity».

- **Annual Produced Electricity**

The Annual Produced Electricity is the electricity annually generated by the power plant during the observation time (in MWh). This electric output is measured at the generator transformer supply voltage terminals.

- **Design Conditions**

The power plant is designed for a specific range of operating conditions. Natural modifications of the geothermal fluid conditions, in terms of pressure, temperature and gas content, can alter the net output from the plant. Power factor, cooling water or ambient air temperatures (seasonal effects) are also specified design conditions, and often the plant operates with these parameters. The electric output should be corrected to account for the above-mentioned deviations.

- **Planned Outage**

A Power Plant or Production Area Outage that has been scheduled well in advance (at least two weeks), and is included in the annual plant outage programme.

- **Forced Outage**

A Power Plant or Production Area Outage that requires the plant to be taken out of service immediately or before the next planned outage.

- **Steam/Brine Production Shortfall**

Condition under which the Steam/Brine production capacity of the geothermal wells is unable to meet the power plant required steam rate.

- **Steam/Brine Supply**

Steam/Brine Supply is the average steam plus non-condensable gas mass flow (in t/h) delivered to the turbine and gas extraction system to enable the turbine to achieve its Maximum Load.

- **Specific Steam/Brine Consumption**

The Specific Steam/Brine Consumption is defined as the ratio of Steam/Brine Supply to Maximum Load.

ENVIRONMENTAL PERFORMANCE INDICATORS FOR

GEOTHERMAL ENERGY

Proposed Environmental Performance Indicators	Samples and comments

General indicators

(also applicable to other types of power plants)

Contribution to the reduction of greenhouse gas emissions **AvCO2 (t/MW/y)** = avoided CO2 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).	* 700 MW geothermal avoids 13 million tons of CO2 in 20 years (i.e. 930 t / MW / year) *(source ORMAT)*
Pollutant emissions during the life cycle (g / kWh) : Q_{CO2}, Q_{SOx}, Q_{NOx} **(g/kWh)** = quantities of CO2, SOx and NOx emitted per kWh during the whole life cycle of the plant	•**CO2** is NOT produced from the human-induced exploitation, but they are NATURAL gas, generated from deep chemical reactions; they are naturally released to the atmosphere in all geothermal/volcanic areas. The natural CO2 soil degassing from a standard geothermal area is of the same order of magnitude of the gas emitted from a geothermal power plant. Geothermal energy does not create new CO2 molecules, but simply concentrates at the chimney the natural emission from deep underground layers •**SOx and NOx** are not present in the geothermal fluid ; only a minor production could be released from the diesel engines during the drilling activity, but is –of course- very limited and not relevant during the production life of the plant

Specific indicators

Q_{H2S} **(g/kWh)** = Emissions of H2S during the life cycle of the plant, in g per kWh	* 1 g H_2S / kWh * H_2S is 1% in volume of the CO2 released : this is a rough world-wide average *(Source : International Geothermal Association (IGA))*

SOCIOLOGICAL PERFORMANCE INDICATORS FOR

GEOTHERMAL ENERGY

Proposed Sociological Indicators	Samples and comments
- Jobs created by the plant (n/MW) : **Nj** = number of jobs (direct / indirect) created by a 1 MW power plant for the different steps: manufacture, installation, operation and maintenance.	• 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. • The number of jobs is not always related to the number of MW. For example, for **geothermal plants**, there is no difference related to the unit size. For each standard Unit (15-30-55 MW) there is a direct O&M personnel of about 30. The indirect personnel is very difficult to estimate: taking into account the construction phase of each component, drilling of wells, building the plant, and the resource assessment researcher, we can easily account for 100/200 jobs related to each geothermal unit, even if for a limited time.
- Providing access to electricity : **Na =** 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).	• 30-40,000,000 people are now having access to geothermal electricity in the world
- 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.	• 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.

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  Tel : +39-050-535891 Fax : +39-050-535893 or 533290 E-mail : igasec@enel.it
* or Bruno Manoha, Chairman of the WEC WG on the Performances of Renewable Energies, at *bruno.manoha@edf.fr*

ANNEX 4

PERFORMANCES OF RENEWABLE ENERGIES : SYNTHESIS OF THE DATABASES EXISTING OR UNDER PROGRESS

Summary :

In order to enable people to compare themselves and improve their performances, the availability of performance databases is necessary. This has been done for many years by WEC PGP for nuclear and fossil-fired power plants, and it continues through PGP Work Group 2 "*Power Plant Availability Statistics*", in charge of the collection and input of power plant performance data into the WEC PGP database.

As far as RES are concerned, we have investigated (mostly through Internet search and discussion with specialists) the databases that already exist or are under development throughout the world. The idea is to try, at least in a first step, to privilege collaborations with existing (and well-chosen) experiences, rather than trying to set up from this point on, new specific WEC PGP databases.

The following presents the databases that we have found. It seems that performance databases, as we should conceive them, **only exist today**:

- for Wind through the **Wind Stats** Newsletter.
- for Photovoltaics through the International Energy Agency (**IEA-PVPS** Task 2).

A database is **under construction** at NERC USA for wind (GADS – co-ordinated by Mike Curley, chairman of WEC PGP WG2).

Other RES databases exist, but they are not specifically devoted to the performance of the plants. It seems in fact that, due to hard competition, people hesitate to provide information on their performances

If the aim of PGP is to set up databases for RES, as it was done in the past for more "classical" power plants, our proposal is that WEC officially contacts the people in charge of these databases (see contacts hereunder), and offers to collaborate with them in order to complete and improve the work already done within these existing databases and by PGP WG3. If it appears that such fruitful collaborations are possible, specialists of each type of RES should be nominated within WEC PGP to operate these collaborations.

Wind

- **Existing performance databases:**

It seems that only one database exists and is running today for wind. The results are presented every month in the publication **WindStats Newsletter**. It is mostly devoted to the European wind farms, but some data is given from other parts of the world (USA, New Zealand…). Unfortunately, no data is collected on the corresponding wind characteristics. Also, no data is available on environmental or sociological aspects.

More can be found on their web site (windstats.com).

***Contacts**:* *Windstats@forlaget-vistoft.dk*

- **Performance databases under preparation:**

NERC (North American Electric Reliability Corporation) is presently setting up a new **GADS** database within **WTWG** (Wind Turbine Working Group), mostly intended to North American data. Mike Curley, chairman of WEC PGP WG2, is in charge of this new initiative.

***Contact**:* *Mike.Curley@nerc.net*

- **Databases on wind characteristics:**

If performance databases are rather few, data on wind characteristics are more numerous. We can mention the following web sites :

- www.winddata.com : this web site of annex XVII of IEA Wind provides data on wind speeds, directions and turbulence, measured for various sites in various countries. Some of them are directly measured on wind farms.
  ***Contact** : RISØ National Laboratory, admin@winddata.com*

- swera.unep.net : the web site of SWERA provides data and maps of wind and sunshine in various countries (Brazil, Bangladesh, Kenya.).
  ***Contact** : UNEP/DTIE-Energy/SWERA*
- www.awstruewind.com : AWS TrueWind is an organisation specialised in the technical applications of renewable energies and proposes some wind maps (with private access).

Photovoltaics

- **Existing performance databases:**

Only one database has been found on the **performances** of photovoltaics: **IEA PVPS-Task2** has prepared in 2000 a report of the International Energy Agency which provides an international database on the performances of PV systems operating in about many countries around the world (Austria, USA, France, Germany, Italy, Israel, Japan, Netherlands, Switzerland,…). The report can be found on www.iea-pvps-task2.org . The current database (version of June 2005) contains data of 431 monitored PV plants and would probably be a very good basis for a perennial database.

Contact *: **Institut für Solarenergieforschung GmbH – Hameln / Emmerthal***

- **Other web sites** give information and data on PV, but they mostly concern **characteristics** of PV systems, not their performances:

- www.photonnes.de : statistics on PV installed capacity and produced electricity in Germany

- swera.unep.net : see wind § up there

- http://re.jrc.cec.eu.int/pvgis/pv/ : this site of the European Commission (Joint Research Centre) provides, for every point (latitude, longitude) in Europe, Africa and South West Asia, maps and values of monthly sunshine, temperature, or optimal inclination of solar panels.

- eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?na : this site proposes NASA meteorology and solar energy data for every point (latitude, longitude) in the world.

- Some **other** databases and payable reports seem to be available on:

- www.pvenergy.com : PV Energy System proposes a report on the technologies, costs and performances of PV systems (« PV Technology, Performance, Cost 1995-2010 »,).

- www.solarbuzz.com : Solarbuzz proposes the same kind of product as PV Energy System (« Marketbuzz 2006 »).

Geothermal energy

No clear and efficient performance database on geothermal energy has been found. Projects are under way but nothing seems to be realised today. We can however mention:

- iga.igg.cnr.it : the International Geothermal Association has made the inventory, country by country, of the installed powers and capacity factors.
  Contacts: *IGA Secretariat at iga@samorka.is*
  We can notice in particular an article http://iga.igg.cnr.it/pdf/WGC/2005/1708.pdf reporting the existence of a database on geothermal energy in the Philippines.

- www.iea-gia.org : the reports of the annex 7 of IEA Geothermal mention a project of international database on the performances and costs of drilling.

Biomass

No general database on the performances of biomass has been found, but **some inventories limited to a given technique** can be found, in particular about gasification:

- www.gasifiers.org : this site makes the inventory of the gasification plants existing throughout the world. It details, unit by unit, the produced electricity, characteristics of the system, used fuels, emissions, number of hours of production per year, …

Contact*: info@gasifiers.org or BTG biomass technology group*

- www.woodgas.com/gdatabase.htm : this site also makes the inventory of the gasification plants but provides less information than the previous web site.

Some other web sites also provide very complete data on the **composition of the fuels, ashes,** …:

- www.ieabcc.nl : the databases of the IEA Bioenergy Task 32 give the composition of:

the fuels (www.ieabcc.nl/database/biomass.php),
the ashes (www.ieabcc.nl/database/ash.php) and
the fumes (www.ieabcc.nl/database/condensate.php)
for various types of fuels. A database providing the characteristics of the co-combustion plants installed throughout the world is also available (www.ieabcc.nl/database/cofiring.php) but no performance data are included.
Contact*: complete list of members available on www.ieabcc.nl/taskmembers.html*

- www.vt.tuwien.ac.at/biobib : this database gives the composition of any type of fuel (with details according to the species of plants) as well as those of their ashes ; however it seems that this database is mostly focused on biofuels.
  Contact*: Technological University of Vienna*

- www.ecn.nl/phyllis : Phyllis is also a database including the composition of fuels (wood, wastes), but it enables to get the characteristics of a mix of fuels (humidity, ashes …) as well.

Contact*: biomass@ecn.nl, Energy research Centre of the Netherlands*

- www.woodgas.com/proximat.htm : woodgas also proposes this type of data, as well as information on gasification.

We can also mention www.epa.gov/landfill/proj/index.htm which collects the US units functioning with gas due to the decomposition of wastes (capacity and avoided CO2, but no other performance data).

Other RES databases

A few other general databases on RES exist, but none seems really satisfactory for our present purpose. Anyway hereunder are some web sites which could be worthwhile:

- www.enerdata.fr : ENERDATA proposes many databases in the field of energy, among which ODYSSEE which seems to be the most interesting. It gathers data on energy efficiency and on CO2 indicators for the European countries.

- www.vgb.org/kissye.html : operated by VGB, KISSYE gathers statistics on the performance indicators of power plants. However it seems to be restricted to Germany and only to fossil-fired, nuclear and co-generators. The big wind farms will probably soon be integrated.

- www.caddet.org : CADDET provides a lot of information on the technologies used for renewable energies. InfoStore in particular is a database of projects sometimes containing technical or performance data. Unfortunately InfoStore is not standardised and has no precise performance indicators. This database could however be useful for a specific precise project.

- www.nrel.gov/analysis/repis : REPiS is a US database providing information on the RES plants. Unfortunately we could not find anything on RES performances, except installed capacity.

Conclusion

In spite of the present enthusiasm for renewable energies and the large number of Internet sites dedicated to them, very little available and useable performance data exists.

The manufacturers, countries and various organisations obviously prefer to communicate on the installed capacities rather than on the real efficiency and performances of the plants.

Finally, only two already existing databases seem satisfactory to us: Windstats for wind farms and IEA-pvps-task2 for Photovoltaics. NERC GADS database in preparation for wind would also be a good basis, provided it extends beyond North America.

Algeria
Argentina
Australia
Austria
Bangladesh
Belgium
Botswana
Brazil
Bulgaria
Cameroon
Canada
China
Congo (Democratic Republic)
Côte d'Ivoire
Croatia
Czech Republic
Denmark
Egypt (Arab Republic)
Estonia
India
Indonesia
Iran (Islamic Republic)
Iraq
Ireland
Israel
Italy
Japan
Jordan
Kenya
Korea (Republic)
Kuwait
Latvia
Lebanon
Libya/GSPLAJ
Lithuania
Luxembourg
Macedonia (Republic)
Mali
Mexico
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russian Federation
Saudi Arabia
Senegal
Serbia
Slovakia
Slovenia
South Africa
Spain
Sri Lanka
Swaziland
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Syria (Arab Republic)
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