WORLD ENERGY COUNCIL
CONSEIL MONDIAL DE L'ÉNERGIE

Performance of Generating Plant: Managing the Changes

World Energy Council 2008

Promoting the sustainable supply and use of energy for the greatest benefit of all

Performance of Generating Plant

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Renewable Energy Plant

Contents

2

Work Group 3
Renewable Energy Plant

Reports on Wind, Photovoltaics, and Biomass Energies

Proposal of Technical, Environmental, and Sociological Performance Indicators for Renewable Energy Sources

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Summary

The work presented here was created within Working Group 3 (WG3) of the World Energy Council's (WEC) Committee on the Performance of Generating Plant (PGP). The main objective is to define performance indicators and produce original guidelines for generating plants using Renewable Energy Sources (RES).

A first phase of the work (1999-2001) proposed technical performance indicators for wind, photovoltaic, biomass and geothermal energy, as has been done in the past by WEC and UNIPEDE for nuclear and fossil-fired power plants. The second phase (2002-2004) has extended the work to proposals for environmental and sociological indicators, as RES are considered particularly beneficial in terms of sustainable development. In the first phase, leading experts in RES, working with international organisations, (IEA, Eurelectric, IGA, WEC, etc.), participated in the work in order to develop standards.

Results of these first phases were presented in reports at the 18th and 19th WEC Congresses, Buenos Aires, October 2001, and Sydney, September 2004. The synthesised results are reviewed in the present report.

The third and final phase of the work, which is presented here, has yielded pioneering reports on wind, photovoltaic and biomass energies, and the previous results on indicators have been completed and finalised.

We hope that these new performance indicators will be useful to all experts, organisations and countries willing to develop renewable energy. It is hoped in particular that this work will help compare the respective benefits and deficiencies of various technologies, analyse and identify their weaknesses, and thus lead to improvements in performance, and finally contribute to a more efficient and rapid development of RES.

Resumé

Le présent travail a été réalisé dans le cadre du Conseil Mondial de l'Energie (CME) et de son Comité sur les performances des centrales de production électrique (PGP). Son objectif principal est de définir des indicateurs de performance pour les filières utilisant des sources d'énergie renouvelable (ENR), et de faire un état de l'art sur ces filières. Une première phase a consisté à proposer des indicateurs techniques pour l'éolien, le photovoltaïque, la biomasse et la géothermie, comme cela a été fait par le passé pour les centrales nucléaires et thermiques classiques par le CME et l'UNIPEDE.

La seconde phase a étendu l'étude à des indicateurs environnementaux et sociologiques, les ENR ayant pour caractéristique de participer fortement à ce qu'on a coutume d'appeler le développement durable. Comme pour la première phase, d'éminents spécialistes ont travaillé à la définition de ces indicateurs, en liaison avec divers organismes internationaux reconnus en la matière (IEA, Eurelectric, IGA, CME, etc.), afin que les indicateurs proposés puissent être considérés comme aussi standard que possible.

Les résultats de ces deux premières phases ont été consignés dans les rapports présentés aux 18ème et 19ème Congrès du Conseil Mondial de l'Energie à Buenos Aires en octobre 2001 et Sydney en septembre 2004. La troisième et dernière phase, dont les résultats sont présentés ici, a permis de compléter le travail par des états de l'art sur l'éolien, le photovoltaïque et la biomasse, et de finaliser le travail précédent sur les indicateurs. Nous espérons que ce travail s'avérera très utile pour toutes les personnes, organismes et pays souhaitant développer les énergies renouvelables. A l'avenir, ils devraient aider à comparer et positionner les différentes techniques utilisées, permettant ainsi de mieux identifier leurs faiblesses éventuelles, d'améliorer leurs performances et d'aider, de façon générale, au développement des énergies renouvelables.

Introduction and Background

The mission of the World Energy Council is “to promote the sustainable supply and use of energy for the greatest benefit of all“. This encompasses, among other things:

- conservation of energy resources;
- protection of the environment;
- strategic future planning;
- assistance to developing countries to help them meet their energy needs.

In the electricity sector, this can also mean the energy demand management, and the development of renewable energy.

The WEC Committee for the Performance of Generating Plant (PGP) was established over 30 years ago to enable the countries and electricity producers to evaluate the respective performances of plants, detect their weaknesses, and gain experience from successful performance improvement efforts of other producers.

Renewable energy is developing rapidly, and it was felt that the time was ripe to begin the same work on this form of energy as well. After a first attempt focused on wind energy only, presented at the 17th WEC Congress in Houston in 1998 [1], a specific Working Group was established in 1999. The first (1999-2001) and second (2002-2004) phases of its work were focused on the proposal of technical, environmental and sociological performance indicators for wind, photovoltaic, biomass and geothermal energies. The results were presented during the 18th and 19th WEC Congresses in Buenos Aires October 2001, and Sydney September 2004 ([2] and [3]). These results are summarised in Chapter 3 of the present report, and in annexes 1, 2 and 3. Annex 3 in particular presents 4-page flyers of proposed performance indicators for each of these four renewable energies.

In order to complete the work, ultimately phase 3, the main objective of the present report was dedicated to the production of state of the art documents on wind, photovoltaic and biomass energies. A global overview is presented on the state of these three main renewable energies. Hydro and geothermal have not been considered here; although important renewable energies, hydro has a long history of study, and geothermal energy has very specific characteristics.

Chapter 4 combines these up-to-the-minute documents for wind, photovoltaic and biomass, in such a format that corresponding documents can be easily and individually extracted from the whole report.

During phase 3, a search was also made on the existing performance databases for RES. This was in order to see if WEC should, in a future phase, set up new databases for RES (as was done in the past for nuclear and fossil-fired power plants), or collaborate with organisations having already developing such work. Annex 4 presents the results of this specific search.

Objective of the Work Group

The objective of the Work Group is to provide information and enable benchmarking for generating plants using renewable energy sources. This is in order to help improve efficiency of the systems and the design of new projects, and enable potential project participants to evaluate and make comparisons in terms of their respective performances.

To fulfil this objective, technical, environmental, and sociological performance indicators are necessary. The first phase of the work group has resulted in a proposal for technical indicators. Environmental and sociological indicators were proposed in the second phase. Currently, some of these indicators are only concepts, which have yet to be more precisely defined and compared with existing or emerging norms and standards.

The general objective of the work is to promote efficient development of Renewable Energy around the world, and to improve the performance of generating plants that utilise them. To achieve this, it was felt that complete overviews of the present states of the art of wind, photovoltaic and biomass energies were necessary to really complete the work. These latest reports were prepared during phase 3 of the work group, and are presented here.

Expected benefits of the study

- Improvements in power plant performance bring many direct benefits, including:
- increased generating capacity;
- fewer (and shorter) outages;
- better power plant economics.

These direct benefits produce equally important secondary benefits e.g. improved confidence in RES technologies, more effective use of existing generating capacity, reduced or deferred need for construction of new generating capacity, and lower overall generation costs. Another benefit can be achieved by means of an improved management process. Sub-standard management is often the reason for poor performance of generating plants and the inability to realise their inherently superior performance potential.

Furthermore, better awareness and knowledge of the environmental and sociological advantages of RES can also improve public acceptability of the systems. Conversely, an early identification of potential problems can help minimise and mitigate compensation claims and thus ensure the development of renewable energy resources in a sustainable manner.

The development of performance indicators is the first step in a process of creating large databases which would enable power plant operators to compare their own plant performances with others, and make improvements. This point will be discussed next in chapter 3.

Technical, Environmental and Sociological Performance Indicators

The list of technical environmental and sociological indicators proposed in the previous phases of the work is reviewed in annex 2. Annex 3 presents 4-page flyers (one for each of the following energies: wind, photovoltaic, biomass and geothermal) summarising the indicators, their definitions and examples of their value. For more details, refer to reports [2] and [3].

Economic indicators have not been proposed and included at this stage of the work, because it seemed a very difficult task taking into account the variety of circumstances, the rapid development of RES and issues of "confidentiality'. However some general economic indications, figures and comments are given in report [3], in order to give a more complete overview of the issues facing RES.

General Comments

The definitions of the proposed indicators will probably have, at least for some of them, to be very precisely defined taking into account existing norms and standards already set for "classical" power plants, so that they can be very clearly understood and used, and be "officially" considered as real standards.

Along with these indicators, general information on the RES plants has to be provided in order to be able to compare and generate useful statistics in the future. In particular, the following data are necessary when introduced in the future databases:

- Age;
- Vintage;
- Type of technology (type of PV cells, of wind turbine wings, of biomass fuel, of geothermal technique);
- Cycle of operation;
- Life time of the plant;
- Payback time / number of years of production of electricity needed for implementation of the plant (especially for PV)
- Wind and PV: type of eventual necessary back-up (fuel, diesel, oil)

Setting Up Databases?

In order to facilitate comparisons and improve the performance; the availability of performance databases is a necessity. Collection of data has been done for many years by 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.

Annex 4 presents a complete review of all 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 tough competition, people are hesitant in providing information.

Latest Expansion and Future Expansion of Renewable Energy

The following elements present the status quo for wind, photovoltaic and biomass:

- Wind energy today
- Photovoltaic energy today
- Biomass energy today

Each component is presented in an autonomous way that can be easily extracted from the whole report. Every flyer contains the following:

- World production and trends per country
- Technologies, performance and manufacturers
- Advantages and drawbacks
- R&D needs
- Investments and production costs
- Incentive systems
- Future potential and production perspectives

The figures given in the report are the latest available at the time of producing the report.

Section 1
Wind Energy Today

1. Wind Energy: A Dynamic Sector

1.1 Current Trends

Since the early 1990s, wind power has undergone a considerable level of development. In 1995, an installed capacity of 5,000 MW was achieved globally. 2005 was another record year for wind energy, with an installed capacity reaching 59,200 MW and 11,700 MW added during the year (i.e. a growth rate of 25%). In 2006, the first statistics show a total capacity of 72,600 MW (13,400 MW installed during the year, i.e. 23% growth rate).

Due to this development the wind power sector represented 3.0% of the total renewable electricity in 2005, behind hydro power (89.5%) and biomass (5.6%). Wind energy delivered around 0.6% of the global electricity generation (98.4 TWh), far behind coal (40%), gas (19%), large hydro (16%), nuclear (15.5%) and oil (7%).

1.2 Asia: the new driver

2006 was a great year for wind energy. Nevertheless the great majority of wind turbines were installed in Europe, despite Asia (+49% in 2005, +30% in 2006) and North America (+33%) showing the highest growth rates, with India overtaking Denmark in absolute numbers of for instance. Europe maintained a leading position but new installations represented 57% of the very latest installations, while having 71% achieved in 2004.

American wind energy fared better; North America enjoyed a new boom and Latin America seems to have become an emerging sector, especially Brazil and Argentina.

The Oceania and African markets were still subdued but with good prospects; the growth rate in Oceania was significant in 2005 but slowed in 2006 and major new projects, particularly in Egypt and Morocco, were launched in Africa which has huge potential.

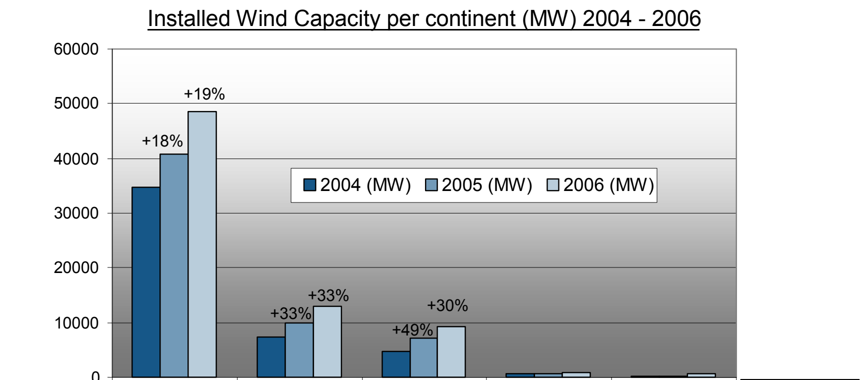
1.3 Major countries

Few countries stand out from the crowd. Germany is the leader with more than 20,600 MW installed in 2006 i.e. nearly one third of the world-wide wind power installation. Thereafter come Spain (11,615 MW installed), the United States (11,600 MW), India (6,050 MW) and Denmark (3,140 MW). These five countries account for nearly 75% of the global capacity in 2006.

However the diversification of the international wind energy markets is progressing. Twelve countries show an installed capacity of more than 1,000 MW (seven in Europe, three in Asia, two in North America), when three years ago only five showed such a capacity.

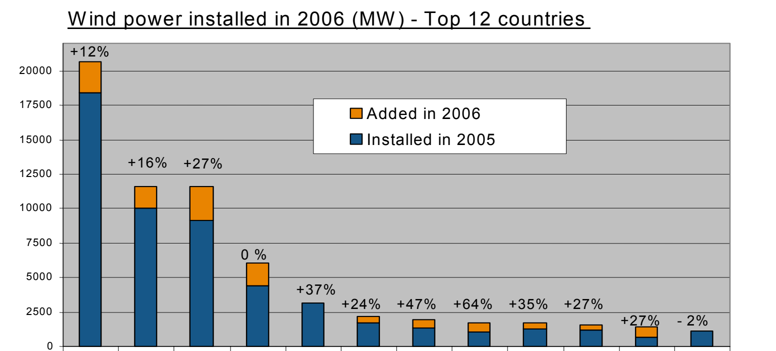
Denmark, which was once the wind industry and is now nearly fully equipped, must support offshore and re-powering projects (replacing old and small wind turbines with new and larger turbines). In addition, the importance of energy policies and establishment of regulatory mechanisms (guaranteed prices, tax credits, capital grants… see §. 6. “Encouraging wind energy development”) must be emphasised. Any change in a country can indeed quickly affect national development of wind energy. Due to fewer incentives, new projects in Germany are annually decreasing. Spain has taken

Figure 1-1



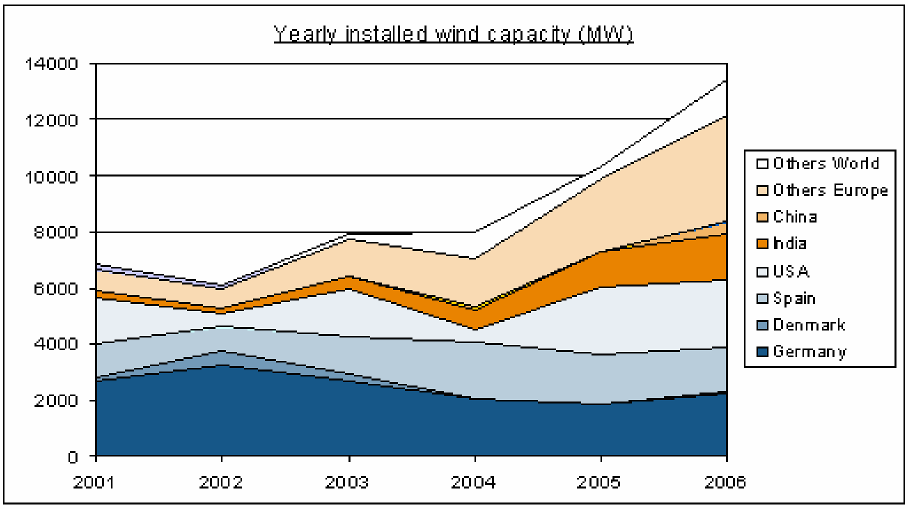
	Europe	N. America	Asia	Oceania	Africa	Total World
2004 (MW)	34,758	7,367	4,759	547	240	47,489
2005 (MW)	40,887	9,833	7,098	740	252	59,235
2006 (MW)	48,531	13,054	9,204	799	661	72,628

Figure 1-2



	Germany	Spain	USA	India	Denmark	Italy	UK	Portugal	China	Netherlands	Canada	Japan
Added in 2006 (MW)	2,233	1,587	2,454	1,619	11	417	631	673	439	336	767	-22
Installed in 2005 (MW)	18,415	10,028	9,149	4,434	3,129	1,718	1,332	1,047	1,260	1,224	684	1,150

Figure 1-3



Sources: Systèmes Solaires – Observ'ER

2. Turbines and Manufacturers

advantage of its positive policy towards renewable energies; the growth rate was particularly high during recent years. Similarly, due to new attractive policies, wind power in Italy, the United Kingdom, the Netherlands, Austria and especially Portugal matured rapidly. Following the new Production Tax Credit system, dynamism was recovered by the US wind energy sector in 2005 and 2006 after a poor year 2004.

2.1 How to harvest the wind?

Wind turbines are machines that convert wind power into mechanical energy for pumping or into electric energy by means of an alternator. Wind turbine systems can be stand-alone (the entire generated electricity is locally consumed) or grid-connected.

Most wind turbines are grid-connected and concentrated inside wind farms, thus forming small and large power plants, e.g. one of the largest wind farms, the Horse Hollow Wind Energy Center in Texas (USA), reaches a capacity of 662 MW.

Most wind turbines are three-bladed and operate "upwind", with the blades facing the wind. Another type of wind turbine is the two-bladed "downwind" turbine, where the generator is mounted in a nacelle at the top of a tower, behind the hub of the turbine rotor.

Offshore wind farms have been operating in Europe for a few years. The essential design of their turbines does not change, but some modifications are necessary to meet offshore wind characteristics (higher energy, lower turbulence), air salinity, waves and current loading at the foundation.

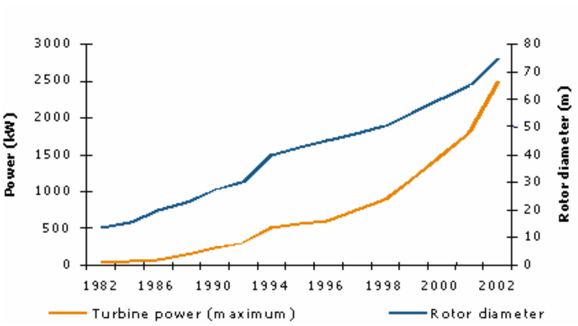
2.2 Modern wind turbines

Over two decades the power and size of installed wind turbines have been significantly increasing annually (see following graph). This growth is now slower for onshore turbines. Typical modern grid-connected wind turbines have diameters of 40 to 90 metres, towers of 50 to 100 metres high and are rated between 500 kW and 3 MW (average: 1.85 MW in Germany in 2006). Their excellent technical availability is between 95 and 99%. Their capacity factor (ratio of the total actual energy production over the potential energy production) is impaired by wind intermittence, usually between 20 and 30% for onshore; it can reach 40% for offshore farms.

Currently the most powerful turbine is rated at 6 MW with a rotor diameter of 115 metres and a tower of 125 metres. The 3 to 6 MW wind turbines are in fact mainly intended for offshore installations. Wind turbines are designed to work for some 120 000 hours of operation throughout a lifetime of about 20 years.

Figure 2-1

Wind Turbine Size Evolution



Source: EDF

2.3 Major manufacturers

Major wind turbines manufacturers are Danish, German, Spanish and American. This market is very tough and competitive. In 2005, Vestas (Denmark) was still the world-wide leader with 28.4% of the market. The US GE Wind came second with 18.1% of the market (only 4th in 2005) thanks to the national market expansion.

Enercon (Germany), with 13.4% of the market,almost maintained its sales level in spite of the German market weakening. The Spanish Gamesa dropped from 2nd place to 4th with 13.2% of the market in 2006.

An outstanding fact is the rapid development of manufacturers in emerging countries. Suzlon (India) became the fifth world-wide manufacturer in 2005 and Goldwind (China) intends to develop a national market before exporting production.

It is now technically possible to build wind turbines in a water depth in excess of 30 metres and far offshore. Nevertheless such an installation is very expensive; so most offshore wind farms are in shallower depths within 18 km. In 2005, an offshore wind capacity of 900 MW was installed in the world.

Figure 2-2

Wind Turbines

Manufacturer	Market Share (%)
Vestas (DK)	29
GE (US)	18
Enercon (Ger)	13
Gamesa (Sp)	13
Suzlon (Ind)	6
Siemens (DK/Ger)	6
Repower (Ger)	3
Nordex (Ger)	3
Ecotecnia (Sp)	2
Mitsubishi (Jp)	2
Others	5

Source: EDF

3. Wind Power: Ideal Solution?

3.1 Wind power assets

Wind energy is a so-called “renewable energy”. It has thus many advantages:

- Wind is free, no fuel need during operation
- No wastes during operation
- No greenhouse gas (GHG) or other polluting gases emissions during operation
- Quick installation
- Lands beneath can usually be used for farming
- Can be a clean solution of supplying energy in remote areas
- Wind energy is a local energy

3.1.1 Greenhouse gas emissions reduction

Wind energy produces no polluting gases during operation. Nevertheless, there are emissions during the manufacture, installation and dismantling procedures. By means of LCA (life-cycle analysis) methods, these emissions can be estimated: 32 kgC/tep, i.e. between 3 and 22g CO2 per kWh produced by the wind system depending on the manufacturing country and electricity production mode.

This figure can be compared with other energy sources: between 800 and 1050g CO2/kWh for a coal power plant, depending on the technology, 430g CO2/kWh for gas power plants, 6-9g CO2/kWh for nuclear power plants (average values)

A wind turbine of 1 MW avoids around 2000 tonnes of CO2 every year in a country where most power plants are run by fossil fuels.

Consequently, wind energy is clean in comparison to fossil fuels and can be instrumental in reducing greenhouse gas emissions and limiting climate change.

3.1.2 Quick Installation

Wind turbines can be quickly and easily installed compared to nuclear, coal or gas power plants and can respond to urgent requests from specific areas.

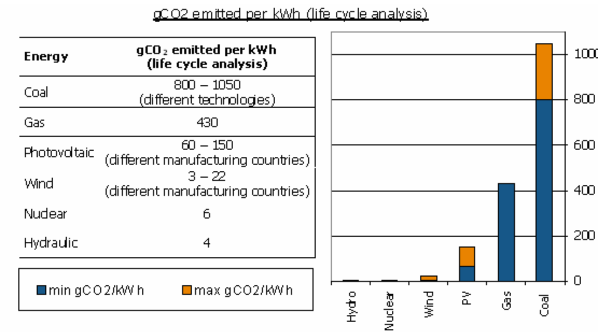
3.1.3 Required land area

The land area required for a 1GW plant depends on the energy source: A wind farm area can also be used for agricultural purposes; the strict area required for the installation of turbines is about 1 km² for 1 GW – similar to coal and nuclear. This low required area could be an advantage. Wind turbines can be quickly and easily installed compared to nuclear, coal or gas power plants and can respond to urgent requests from specific areas.

3.1.4 A local energy

Wind energy can help to build energy independence; as there is no fuel price risk or import dependence, this results in nil resource constraints. Generated locally, wind energy can also create long-term local employment and sources of income.

Figure 3-1
CO2 Emissions



Source: Jancovici

Table 3-1
Renewable Land Use

Type	Wind	Solar (PV)	Biomass	Geothermal
Area Required for 1 GW Power Plant (avg km^2)	100	30	5000	200

Source: WEC and US D.O.E.

Moreover, this local independence eliminates the risks of conflicts which may arise from sharing of a scarce resource between different users, at a regional or national scale (which is sometimes the case for hydro or fossil fuels).

Although wind energy has many interesting assets, wind does not blow constantly and cannot provide a continuous energy supply. This intermittence is one of the principal drawbacks of wind energy.

3.2 Wind power drawbacks

Wind energy seems to be faultless but has several major drawbacks:

- Intermittence
- Grid connection
- Difficulty to forecast wind conditions
- Visual impact
- Noise impact
- Other environmental impacts

3.2.1 Intermittence

A wind farm usually generates electricity corresponding to around 1800-2600 hours at full load per year, which means an average capacity factor of 20 to 30% (more for offshore farms). In the downtime wind energy must be substituted by another quickly available energy source, (shut downs are unforeseeable), or by stored energy, which can in some cases drastically increase the costs and the GHG emissions.

Storage – if estimated as an economic solution - can be chemical (batteries) or physical (hydro), but conversion yields are low and storage capacities are relatively limited. Moreover battery manufacturing requires significant quantities of electricity and therefore emits GHGs.

Instantly accessible energy sources such as fossil fuel power plants have huge GHG emissions and hydro power plants limited capacities. Nuclear plants cannot be easily shut down and restarted and cannot replace wind turbines. However, numerous studies have shown modest extra reserve requirements in many cases.

Wind energy can thus play a significant role in countries where most power plants are run on fossil fuels, but it cannot completely replace these energy sources.

3.2.2 Grid connection

Wind farms are usually installed in remote areas with small capacities, low population density and have intermittent production. Grids may therefore require strengthening and extension. Wind turbine installation is quite rapid compared to gas or coal power plants.

3.2.3 Wind forecasting

Wind energy performance is weather dependent and accurate forecasting is fundamental for economic and viable operation. Unfortunately current long-term wind forecasts are insufficiently accurate and optimal grid management is difficult.

3.2.4 Environmental impacts

If wind turbines emit no GHGs or other gaseous pollution there are still environmental impacts:

Noise impact: Even with notable improvements the noise can still disturb local inhabitants. Precautionary measures have to be taken before making any installation in a populated area and it is essential that a minimum distance is established.

Visual impact: Installations are often coastal or on crests of hills (stronger wind). This can create a negative visual impact, while dwellings in close proximity may suffer from shadow. Ultimately, visual impact is subjective and must be studied frequently on a case-by-case basis.

Bird and bat fatalities: The number of bird deaths depends primarily on site conditions and measures must taken to minimise fatalities; colouring blades and bird repellent measures. One of the main recommendations is to avoid siting installations on migratory routes and nesting places. Bats have been less studied but seem to suffer as much as birds.

3.3 Specific offshore wind energy assets and drawbacks

Presently the great majority of wind turbines is onshore. However in order to solve some wind energy problems there are several compelling reasons for moving the technology offshore:

- Offshore wind is a higher-quality resource: turbulence is reduced, wind speed increased and an offshore wind turbine usually generates electricity around 3500 hours per year instead of 2000 hours for a well situated onshore wind turbine.
- Wind turbines can be installed close to demand centres: many of which are near the coast.
- Offshore energy has the potential for reducing land use and aesthetic concerns
- Offshore technology could reduce scaling concerns in transportation and erection

Nevertheless, offshore wind energy has, owing to the marine background, some specific drawbacks:

- effects on navigation, fishing, aquatic fauna and flora. Offshore installations are fairly recent and studies are rare and need development.
- Transportation of electricity to the coast can generate technical and environmental problems.
- And, last but not least, offshore costs are much higher.

Wind energy drawbacks are thus rather numerous but can be remedied: this is the reason for the continued activity in the wind energy R&D sector. Improving wind forecasts, grid connection and reducing the environmental impacts are essential in order to guarantee that wind energy is a good prospect.

4. R & D Needs for Wind Energy

Wind energy technology is mature, and manufacturers now use the three-blade upwind design where no technological rupture is really expected.

However forthcoming developments are numerous and are summarised as follows

4.1 Turbines optimisations and cost reduction

- Increasing size and power
- Improving the reliability
- Improving blades and towers design
- Optimising the manufacturing technology
- Improving transport and installation techniques

4.2 Offshore specific improvements

- Reducing groundwork cost
- Finding solutions for groundwork in deeper water
- Optimising maintenance techniques
- Developing floating offshore wind turbines
- Developing multi-rotor offshore wind turbines

4.3 Reduction of environmental effects

- Developing low-noise blades
- Monitoring effects on fauna and flora (birds, bats, aquatic life.)
- Minimising visual impact

4.4 Increasing the value of useful wind energy

- Improving wind forecasts
- Improving grid connection
- Improving SCADA systems and controllability of large wind farms
- Developing modelling tools (wind turbines adapted to site conditions)
- Optimising and developing new energy storage systems

4.5 Finding new sites

- Assessing offshore resource
- Assessing resource in mountainous areas
- Assessing resource in cold climates
- Developing designs, materials and methods adapted to extreme external conditions

All these areas need R&D attention for wind power technology to develop further, improve the generating quality and reduce costs. These requirements are "a must" if wind energy is to supply clean, competitive produced electricity.

Sources: EUREC, EWEA, IEA

5. Wind: Cheap Renewable Energy

Wind energy cost depends on the country of installation, manufacturing costs, the wind turbine situation and other factors. The below-mentioned costs are averages of European installations and must be viewed in order of magnitude.

5.1 Investment costs

Initial investment comprises the project study and management, wind turbine purchase, infrastructure (foundations, access to wind turbines, power lines), installation and the start-up costs. Dismantling costs are not considered here since they are nearly negligible and quite insignificant compared to fossil or nuclear energies: they are indeed reasonably well covered by the wind turbine scrap value. The following diagram shows the cost structure for the installation of a typical onshore wind turbine (about 1-1.5 MW) in Europe:

Wind energy project investment costs correspond principally to the turbine costs: the wind turbine itself represents about 75% of the cost, and the infrastructure, installation and project management 25%.

In 2005 this initial investment represented between 900 and 1150€ per kW installed in Europe and about 1300€ in North America. This cost has regularly decreased over the past years but a maturing market will probably cause a gradual decrease unless there is a dramatic increase in raw material price.

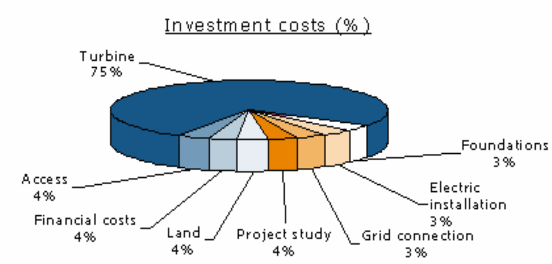
Nevertheless, costs vary for similar generators: these depend on the hub height and the rotor diameter. A wind turbine with a large rotor diameter designed for a low wind speed area will be more expensive than a turbine with a small diameter designed for a high wind speed area. Moreover, costs will be usually higher for isolated wind turbines than for wind farms unless the grid is strengthened and extended.

5.2 O&M costs

Wind turbines are designed to work for some120 000 hours of operation throughout their design lifetime of about 20 years. However, some components can wear down, especially blades and gearboxes where replacement represents between 15 and 20% of the initial turbine cost.

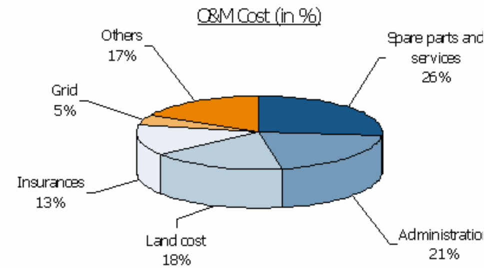
O&M costs include service, repair, new parts, insurance and administration. They represent generally about 1.2-1.5c€ per produced kWh, in other words 20 to 25% of the produced kWh total cost. They are lower when the turbine is new (10-15%) and increase with time (up to 20-35%). For new turbines, the maintenance annual cost will represent about 2.5% of the initial investment in 2007 (source: AWEA and ADEME). Figure 5-1 shows the O&M cost structuring for a typical onshore wind turbine (about 1-1.5 MW) in Europe.

Figure 5-1
Investment Costs



Source: EWEA

Figure 5-2
O&M Costs



Source: EWEA

5.3. Onshore and offshore wind energy cost

Offshore wind energy production is currently much more expensive than onshore. Initial investment is 50 to 100% higher depending on site (depth, distance from shore, type of substratum). O&M costs are also 50 to 100% higher depending on the site.

With O&M costs representing 25% of the kWh cost, wind energy differs from other energies, such as coal or gas, for which only fuel correspond to 40 to 60% of the total cost. In order to estimate the real cost of wind energy, which is intermittent, the country and the local back-up resources must be carefully considered.

The kWh cost for onshore production is estimated between 5 and 12c€/kWh depending on the turbine size and site whereas offshore production cost is estimated between 8 and 20c€/kWh. Thus onshore wind energy production can compete with coal, gas and nuclear electricity and other energies which cost between 3 and 6 c€/kWh, all the more as external costs (impact on human health, ecosystems and global warming) are not considered here: Wind energy, with low external and production costs is an attractive clean alternative to fossil energies

Table 5-1
Investment Cost by Type

Type of plant	Investment costs (€ /kW)	Production costs (€ /MWh)	External costs (€ /MWh)
Nuclear	800-1600	25 - 30	2.3 - 18.8
Coal	800-1200	30 - 35	19 - 99
Gas	350-650	35 - 60	7 - 31
Large hydro	~2000	30 - 65	0.04 - 6.03
Geothermal	1400-1700	50 - 80	0.2 - 0.5
Biomass	1350-2200	40 - 110	2.0 – 50
Wind (onshore)	900-1300	50 - 120	0.5 - 2.6
PV connected	4000-9000	250 - 650	1.4 - 3.3

Sources: European Commission ExternE 1999, IEA

6. Encouraging Wind Development

6.1 General statement

The use of renewable energies is essential to reducing GHG emissions without decreasing electricity production. Unfortunately RES are generally more expensive and must be supported by incentives and positive energy policies.

Before detailing the different incentive schemes, let us note that a massive shift to renewable energies may also demand radical change in people's mindsets. People must play their part in changing the energy landscape and awareness campaigns and other events in the energy policies are promoted by some countries.

Given that renewable energy technologies are often quite recent, countries sometimes choose to support research and development in this field.

Nevertheless, even if these measures bear fruit, they are insufficient and must be integrated with regulations and incentives for the energy utilities.

6.2 Main incentive systems (Source: ECN)

In general, there are two different support types: the authorities can either compel the utilities to produce electricity from renewable energy sources (quotas obligations with penalties, fossil fuel taxes) or financially support renewable energy use (capital grants, tax credits, guaranteed prices).

6.2.1 Quota obligations and renewable energy targets

A growing number of countries have renewable energy targets (see the complete list in Annex 2). Such obligation schemes aim to increase the demand for renewable energy with a percentage or amount of electricity supply that has to be generated from renewable energy by 2010, 2020 or 2030. For instance, the European Union aims at achieving a 20% electricity output from renewable energy sources by 2010, and Australia an annual output of 9,500 GWh in the same period. Quota obligations involve penalty systems to compel electric utilities or authorities to stand by their commitment.

Obligation systems are often related to "Tradable Renewable Energy Certificates" which provide compliance flexibility. These certificates correspond to the value of electricity produced from renewable energy, can be separated from the sale and traded in order to be in compliance.

If renewable energy targets are relatively common, penalty systems (where they exist) are often not stringent enough to be really efficient. Therefore many governments support renewable energy development in conjunction with other systems.

6.2.2 Feed-in / Guaranteed Prices

Under the feed-in system, the government sets the price of electricity produced from renewable energies and utility companies are obliged to purchase this at a set price. Production costs depend on the energy production type, so the guaranteed price differs depending on the technology. This tariff is offered for a period of time and may decrease in due course.

Renewable energy development in the European Union has been principally supported by such feed-in systems, especially in Denmark, then in Germany and Spain, and are now favoured throughout the world.

If the set price is high enough, this system can lead to sustained and significant growth, as in Germany or in Spain. However, and this is the main criticism, if the price is set too high this may provide excess profit to producers at the expense of consumers.

6.2.3 Bidding systems

Bidding (or tendering) systems conform to a government-administered competitive bidding process whereby renewable energy developers compete for access to power purchase agreements and/or to government-administered funds. Contracts are then signed for the most competitive bids and utility companies are often obliged to purchase electricity at the price contracted under the winning bids. Hence there are invitations to tender for different renewable energy technologies, e.g. the USA, China, France and the UK have used such systems.

Such bidding systems result in cost efficacy and price reduction through competition between developers, but are not yet completely satisfactory in comparison to feed-in systems, possibly because of overly complex procedures or because of too few tenders.

6.2.4 Capital grants and other financial subsidies

Wind energy power plants need important initial investment. Consequently governments often apply financial incentives to use this energy, such as grants, as a percentage of total investment or €/kW grants.

The use of investment grants has been a common type of support for some years, probably because this support mechanism is easy to administer.

Due to the fact that some plant owners are not encouraged to operate as efficiently as might be the case using production-based financial support, some countries have begun to offer financial subsidies on a production basis

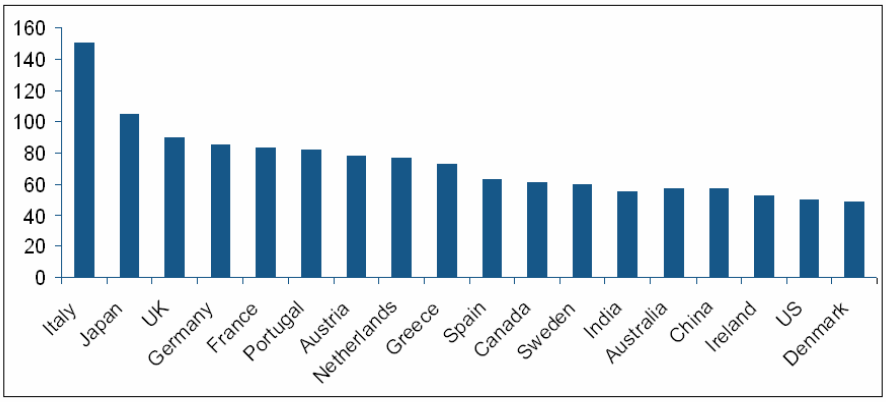
6.2.5 Tax credits

In order to develop renewable energies, many countries apply tax incentives e.g. tax refunds for renewable electricity production, exemption of income/corporate taxation for investments in renewable power producing plants or exemption energy taxes.

Such incentives may relate to investment or production of these energies and improving competition can be easily introduced and adjusted according to circumstances, by the authorities.

Figure 6-1

Onshore Wind Energy Renumeration (€/MWh)



Source: EDF (Note: In order to compare the different systems, it is essential that the time period is also included e.g. in Germany the subsidies are paid for a period of 20 years, and in Italy only 8 years.)

6.2.6 Green marketing

Green marketing is not really an incentive because it depends only on consumer choice e.g. consumers voluntarily pay a premium for renewable electricity only. This premium represents the additional generation cost of such electricity. Under this system public awareness and willingness are obviously the crucial factors.

For the time being green marketing has not yet generally succeeded in creating a large demand for renewable electricity.

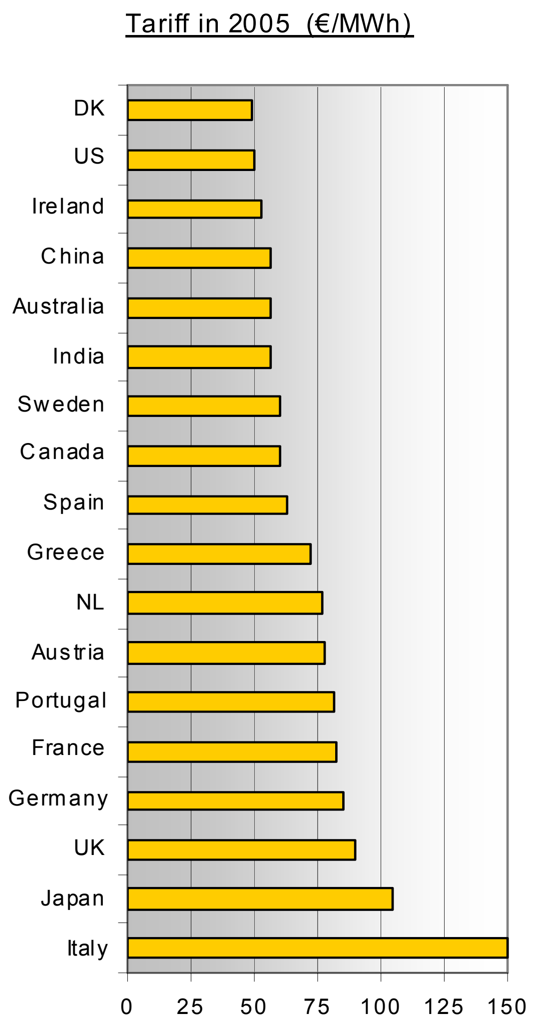
6.3 Wind energy remuneration conditions in some countries

The above diagram shows onshore wind energy remuneration conditions in some countries in 2005. Depending on wind farm age and performance, tariffs decrease over time in France, Germany and Portugal.

The United Kingdom, Italy and Belgium use tradable renewable energy certificates (TREC). Tariffs take these TRECs into account. The United States tariff takes the Production Tax Credit system that represents about 18 €/MWh into consideration. Some countries introduce specific remuneration schemes for the use of offshore wind energy (Germany) or for re-powering projects (Germany and Denmark).

Figure 6-2

Country	Tariff in 2005 (€/MWh)	Remarks
Italy	150	TREC system
Japan	105	
UK	90	TREC system
Germany	85	Tariff onshore for the 5 first years
France	83	Tariff onshore for the 5 first years
Portugal	82	Tariff onshore for the 2000 first hours/year
Austria	78	Tariff onshore for the 13 first years
Netherlands	77	
Greece	73	
Spain	63	Addition al local subsidies
Canada	61	
Sweden	60	
India	50 to 60	Tax credit system
Australia	57	
China	57	Bidding system
Ireland	53	
US	50	Tax credit system
Denmark	49	



When comparing the different systems, it is essential to consider the time period, e.g. in Germany the subsidies are paid for 20 years and in Italy only for 8 years.

7. Breath of Fresh Air for Wind Energy

7.1 Long term wind energy potential

Long term wind electricity production is estimated at 4,500 TWh per year, in other words 27% of world-wide electricity production in 2003 (16,570 TWh). This is lower than for biomass (11,000 TWh) and hydro (7,500 TWh), and approximately identical to solar energy (4,000 to 4,400 TWh).

Nevertheless, if 57% of the hydro potential is already exploited, wind energy is barely exploited today; only 80 TWh were produced throughout the world in 2004. Consequently the wind energy sector will achieve high growth for some years before running out of available space. Wind energy has indeed several assets:

- Wind technology is mature and reliable
- Manufacturers operate on all continents and provide different sizes of wind turbines
- Investment costs are quite low (about 1,000 €/kW for onshore installations and 1800 to 2000 €/kW for offshore installations) in comparison with other renewable energies (for instance, hydro investment costs: > 2,000 €/kW)
- international standards for wind turbines are guarantees of reliability, productivity and security for installation finance

With such benefits wind energy may become one of the most attractive renewable energies by 2030.

7.2 Capacity and production forecasting

If we exclude hydro and biomass energies, wind and photovoltaic solar energies will probably be the major renewable energies in the next decades. Wind energy production can reasonably be expected to reach about 1,000 TWh (700 TWh from onshore installations and 300 TWh from offshore TWh) by 2030. Some optimistic assumptions expect such a level to be achieved by 2020.

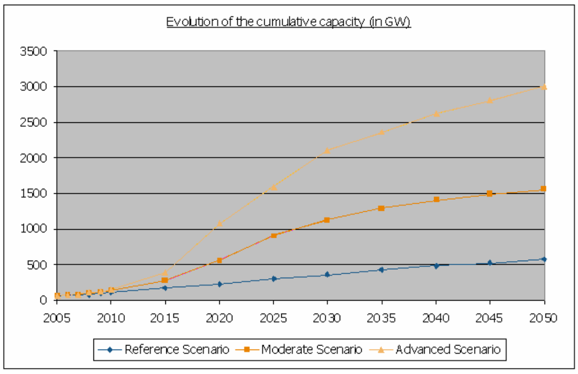
This development will take place in many countries be international. Apart from the two pioneer countries (Germany and Denmark) whose markets are almost oversupplied, other countries will undergo a high level of development.

The following graphs follow three scenarios (reference, moderate and advanced) developed by the GWEC (Global Wind Energy Council) that show installed capacities and electricity production in the world by 2030.

In the reference scenario based on figures from the International Energy Agency (IEA), Europe is still the leader in 2030 with 51% of the wind energy market which can supply 5% of the world's electricity by 2030.

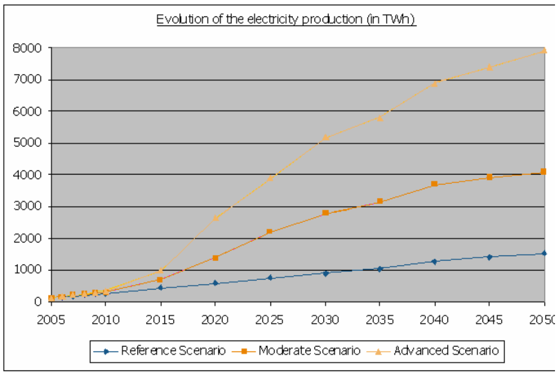
In the moderate scenario, which assumes that current targets for renewable energy are successful, Europe loses some market shares (26% in 2030), North America becomes leader and Central/South America, China and India enjoy

Figure 6-3



Source: GraphicSource Style

Figure 6-4



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important development. Wind can then supply 15.6% of the world's electricity by 2030.

The advanced version assumes that all policy options in favour of renewable energies have been adopted and a stronger spotlight is beamed on Asia and South America. In this case Wind energy can supply 29.1% of the world's electricity by 2030.

With 1375 TWh produced from wind turbines throughout the world in 2020 (moderate scenario), the wind sector would enable to avoid 825 Mtonnes of CO2 per year. However wind energy would only represent 15.6% of the total production and this alone will be still insufficient. Wind energy must be a part of an energy mix.

8. Conclusions

R&D centres are currently particularly interested in energy production by both onshore and offshore farms, which is certainly of potential global importance and should enjoy significant development in the coming decades.

Developed countries, as well as China, India and soon Brazil, will rapidly increase their installed capacity. Pioneer countries in the field (Germany and Denmark) have almost exhausted their available space for onshore installations. Spain, Austria, Ireland and the Netherlands will probably be in the same situation by 2010 and at this point in time these countries will develop their offshore installations where possible.

Technically, no rupture breakthroughs are expected and it is presumed that costs will gradually decrease with widening production and manufacturing improvements, unless raw material prices increase drastically. Ultimately incentive mechanisms are needed to locate new markets and accelerate expansion of the wind energy sector.

This clean and relatively cheap energy will represent the first step towards reduction of GHG emissions. However, owing to potential intermittence, wind energy alone will be unable to supply the entire electricity demand. A clean energy mix, which would combine renewable energies (wind, solar, biomass, marine and geothermal) with nuclear, hydro and other energies, depending on local and regional capacities, is absolutely necessary in order to guarantee a sufficient electricity production and significantly reduce GHG emissions.

Appendix A

2005 Wind Installation Figures

Country	Added 2005	Growth (%)	Installed Capacity (MW)	Country	Added 2005	Growth (%)	Installed Capacity (MW)
Germany	1,798.8	10.8	18,427.5	Brazil	4.8	20.0	28.6
Spain	1,764.0	21.3	10,027.0	Czech Republic	11.5	69.7	28.0
USA	2,424.0	36.0	9,149.0	Argentina	1.2	4.7	26.8
India	1,430.0	47.7	4,430.0	Latvia	0.0	0.0	26.7
Denmark	4.0	0.1	3,128.0	Jamaica	0.0	0.0	20.7
Italy	452.4	35.8	1,717.4	Turkey	0.0	0.0	20.6
United Kingdom	465.0	52.4	1,353.0	Tunisia	0.0	0.0	20.0
China	496.0	64.9	1,260.0	Colombia	0.0	0.0	19.5
Netherlands	141.0	13.1	1,219.0	Gouadeloupe	0.0	0.0	19.3
Japan	143.8	16.0	1,040.0	Hungary	13.8	423.1	17.0
Portugal	500.0	95.8	1,022.0	South Africa	0.0	0.0	16.6
Austria	213.0	35.1	819.0	Russia	3.2	29.7	14.0
France	371.2	96.2	757.2	Curacao	0.0	0.0	12.0
Canada	239.0	53.8	683.0	Switzerland	2.9	33.0	11.6
Greece	100.3	21.2	573.3	Bulgaria	0.0	0.0	10.0
Australia	193.0	50.9	572.0	Israel	0.0	0.0	7.0
Sweden	57.9	12.8	509.9	Lithuania	0.0	0.0	7.0
Ireland	157.1	46.4	496.0	Crotia	0.0	0.0	6.0
Norway	0.0	0.0	270.0	Slovakia	0.0	0.0	5.0
New Zealand	0.1	0.1	168.2	Faroe Islands	3.9	2600.0	4.1
Belgium	72.4	76.2	167.4	Cape Verde	0.0	0.0	2.8
Egypt	0.0	0.0	145.0	Nigeria	0.0	0.0	2.2
Korea (Rep.)	96.6	428.6	119.1	Mexico	0.0	0.0	2.2
Chinese Taipei	90.0	692.3	103.0	Chile	0.0	0.0	2.0
Finland	0.0	0.0	82.0	Cuba	0.0	0.6	1.8
Poland	10.0	15.9	73.0	Jordan	0.0	0.0	1.5
Ukraine	4.2	6.0	73.0	Belarus	0.0	0.0	1.1
Costa Rica	0.0	0.0	69.9	Romania	0.3	41.7	0.9
Morocco	10.1	18.7	64.0	Syria	0.0	0.0	0.8
Luxembourg	0.0	0.0	35.3	Eritrea	0.8		0.8
Iran	6.6	26.5	31.6	Peru	0.0	0.0	0.7
Indonesia	27.4	913.3	30.4	Namibia	0.2	1150.0	0.3
Philippines	0.0	0.0	29.0	Uruguay	0.0	0.0	0.2
				Total	**11,310.3**	**23,7**	**58,981.6**

Source: WWEA

Appendix B

2006 Worldwide Renewable Energy Targets

Country	Renewable Energy Targets (TPES: total primary energy supply)
Australia	9,500 GWh of electricity annually by 2010
Austria	78.1% of electricity output by 2010
Belgium	6% of electricity output by 2010
Brazil	Additional 3,300 MW from wind, small hydro, biomass by 2016
Cyprus	6% of electricity output by 2010
Czech republic	5-6% of TPES by 2010, 8% of electricity output by 2010
Denmark	29% of electricity output by 2010
Indonesia	5.1% of electricity output by 2010
Finland	35% of electricity output by 2010
France	21% of electricity output by 2010
Germany	12.5% of electricity output by 2010
Greece	20.1% of electricity output by 2010
Hungary	3.6% of electricity output by 2010
Ireland	13.2% of electricity output by 2010
Israel	2% of electricity output by 2007, 5% of electricity output by 2016
Italy	25% of electricity output by 2010
Japan	7% of TPES by 2010
Korea	2% of total energy consumption by 2006
Latvia	6% of TPES (excl. large hydro) by 2010, 49.3% of electricity output by 2010
Lithuania	12% of TPES by 2010, 7% of electricity output by 2010
Luxembourg	5.7% of electricity output by 2010
Mali	15% of TPES by 2020
Malta	5% of electricity output by 2010
Netherlands	9% of electricity output by 2010, 10% of primary energy by 2020
New Zealand	30 PJ of new capacity (including heat and transport fuels) by 2012
Norway	7 TWh from heat and wind by 2010
Philippines	Increase in renewables of 4.7 GW of total existing capacity by 2013
Poland	7.5% of TPES by 2010, 14% by 2020, 7.5% of electricity output by 2010
Portugal	45.6% of electricity output by 2010
Singapore	50,000 m² of solar thermal systems by 2012, complete recovery of energy from waste
Slovak Republic	31% of electricity output by 2010
Slovenia	33.6% of electricity output by 2010
South Africa	10,000 GWh or 0.8 Mtoe by 2013
Spain	30.3% of electricity output by 2010
Sweden	60% of electricity output by 2010
Switzerland	3.5 TWh from electricity and heat by 2010
Turkey	2% of electricity from wind by 2010
United Kingdom	10% of electricity output by 2010

Source: IEA

Appendix C

Bibliography

- EDF – Electricité De France documents, www.edf.fr
- IEA – International Energy Agency, www.iea.org
- REN21 – Renewable Energy Policy Network for the 21st Century, www.ren21.net
- EWEA – European Wind Energy Association, www.ewea.org
- AWEA – American Wind Energy Association, www.awea.org
- ECN – Energy research Centre of the Netherlands, www.ecn.nl
- NREL – National Renewable Energy Laboratory, www.nrel.gov
- Windpower – Danish Wind Industry Association, www.windpower.org
- Ministère de l'Economie, des Finances et de l'Industrie, www.industrie.gouv.fr
- European Commission, ec.europa.eu
- DOE – US Department of Energy, www.energy.gov
- WEC – World Energy Council, www.worldenergy.org
- Ministère de l'Ecologie et du Développement Durable, www.ecologie.gouv.fr
- ADEME – Agence de l'Environnement et de la Maîtrise de l'Energie, www.ademe.fr
- GWEC – Global Wind Energy Council, www.gwec.net
- WWEA, World Wind Energy Association, www.wwindea.org
- Jancovici Website, www.manicore.com
- IEA Wind, www.ieawind.org
- Observ'ER, www.energies-renouvelables.org
- IFREMER, Institut Français de Recherche pour l'Exploitation de la Mer, www.ifremer.fr
- DTI – Department of Trade and Industry, www.dti.gov.uk
- BWEA – British Wind Energy Association, www.bwea.com
- Royal Academy of Engineering, www.raeng.org.uk

Section 2
Photovoltaics
Energy Today

1. Photovoltaics: A Booming Sector

1.1 Current trends

Over the past fifteen years, photovoltaic (PV) solar energy has demonstrated an exponential development. Once a leading-edge technology only used for artificial satellites, PV cells are becoming more accessible every day.

In 1992, a capacity of 110 MWp (MWp: MW peak, power supplied by solar cells in normalised conditions – an in-plane irradiance of 1 kW/m² and a cell temperature of 25°C.) was installed in the world. By the end of 2005, a cumulative installed capacity of 4,640 MWp was achieved with 1,460 MWp added during the year, in other words an outstanding growth rate of 34%. Solar PV is the fastest growing power generation technology.

However, counting PV systems is more difficult than counting evaluating alternatives. They are smaller, plentiful, often directly installed on scattered private roofs and rarely assembled in an industrial plant.

Despite this huge growth, PV energy is still insignificant in the renewable energy mix: the PV sector represented only 0.1% of the total renewable electricity, far behind hydro power (90.4%), biomass (5.2%) and wind power (2.6%). PV energy delivered only 0.01% of the global electricity, compared to coal (40%), gas (19%), large hydro (16%), nuclear (15.5%) and oil (7%).

1.2 A market focused on few countries

Historically, Japan was one of the first countries to massively support PV energy. Its cumulative capacity in 2005, with 1,430 MWp, represents 31% of the world-wide PV energy installations.

However, over the past two years, Germany has become the largest market, representing 58% of the new installations world-wide in 2005 and a cumulative capacity (1,910 MWp in 2005 for the AGEE Stat, and 3,063 MWp for Photonnes International by the end of 2006) which overtakes the Japanese capacity.

The United States is the third largest market with 105 MWp installed in 2005 and a cumulative capacity of 465 MWp. Far behind Germany, Japan and the United States, come the two Asian giants India and China.

In Europe, many countries are interested in photovoltaic energy development. Apart from Germany, they are small markets at present, but PV is at its pinnacle and should achieve a high level of development in a few years.

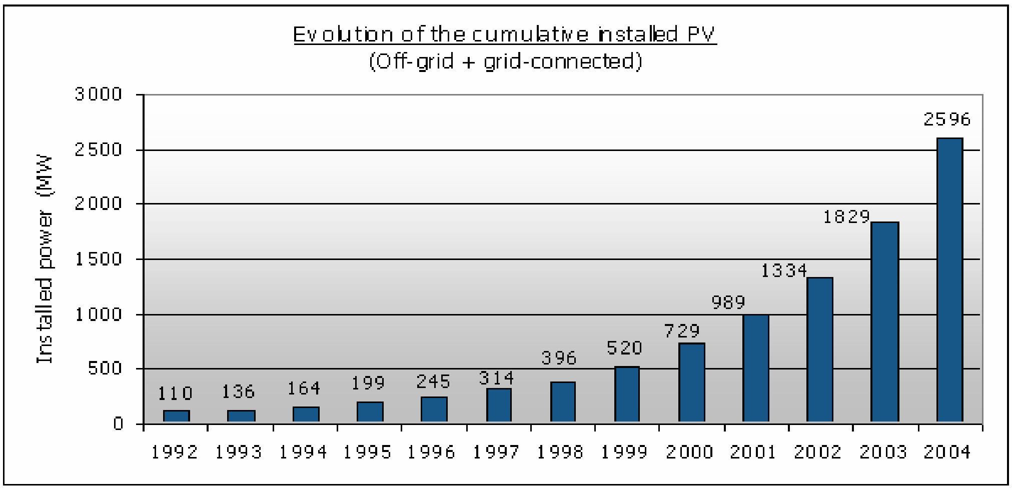


Figure 1-1
Capacity Evolution

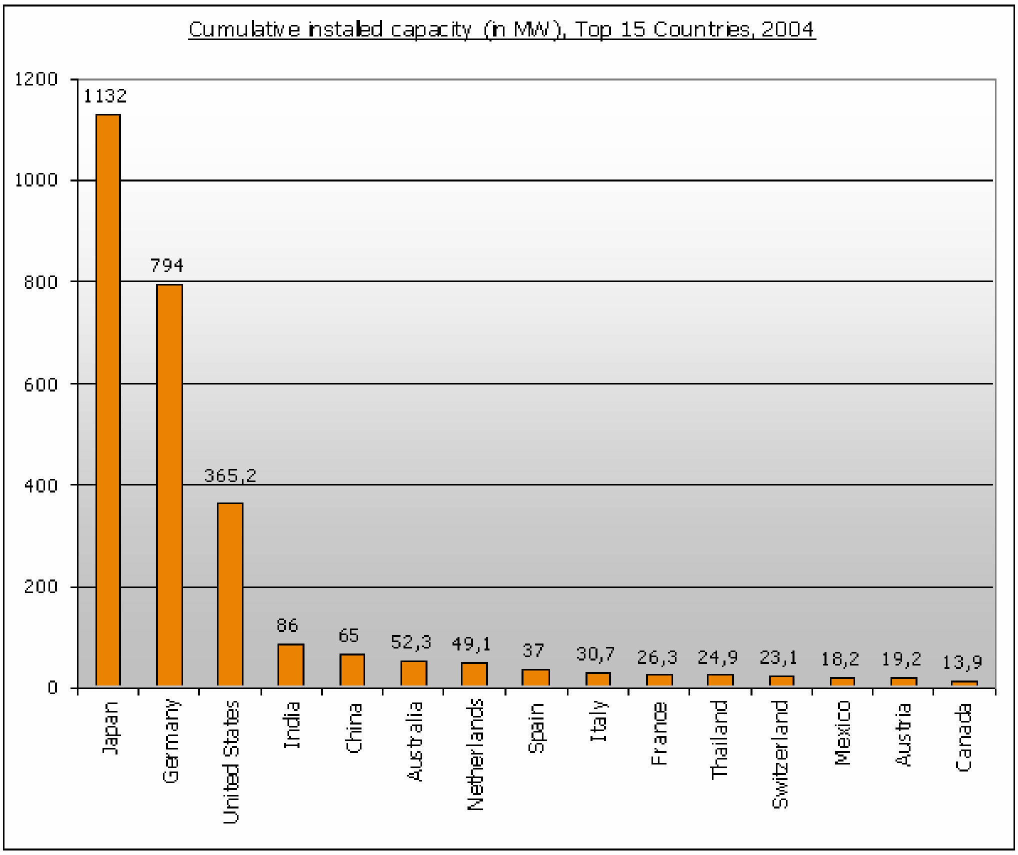


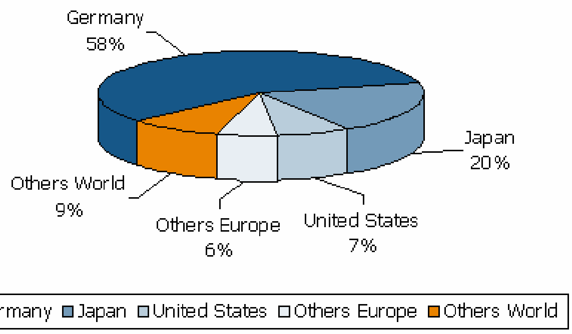
Figure 1-2
Market Capacity

Source: IEA

Figure 1-3
Solar Installations

Worldwide new installations in 2005

Country	Added in 2005 (MWp)
Germany	837
Japan	292
United States	105
Others Europe	89
Others World	137



Source: Marketbuzz 2006: Solarbuzz

1.3 Influence of energy policies (for further information, see sub-section 6)

PV energy is still expensive and needs incentives. Energy policies and establishment of regulatory instruments (guaranteed prices, tax credits, capital grants…, see §. 6. Encouraging PV energy development) are essential. Besides, there is a correlation between new installations and energy policies. Any change in national policy can thereby quickly affect PV energy national development.

In this way, a law in favour of grid-connected PV systems largely supports the German PV sector. The introduction of this law generated a considerable boom in PV system installation. France, Spain and Italy recently adopted similar positive regulations and should become important markets in the future.

Alternatively, Japan stopped national incentives for PV installations, and this slows down the growth of the Japanese PV market.

After a poor performance in 2004 and 2005 compared with Japanese and European markets, the US PV market should soon experience a high growth rate given positive photovoltaic development programmes in some States (especially California, New Jersey and Nevada)

Finally China, which currently has a small emerging market, should become one of the major countries by 2010 with the introduction of PV development programmes (principally in municipal solar roof): a capacity of 500 MW can be expected in 2010.

2. PV and Leading-Edge Technologies

2.1 PV system: how does it work

A PV system uses panels of solar cells, which directly convert solar power into electricity. These cells consist of two thin chemically treated layers of semi-conducting materials

that react with sunlight to produce electricity: when it shines on the cell, an electric field is created across the semi-conductor layers. This process is called “photovoltaic effect”.

PV systems can be stand-alone or grid-connected. Previously, PV panels were extremely expensive, too much for grid connection. This means that the greatest numbers were used for stand-alone PV systems since they were (and still are) good solutions for use in remote areas, especially where the consumption was far from the nearest power lines. These systems produce and store power independently from the grid.

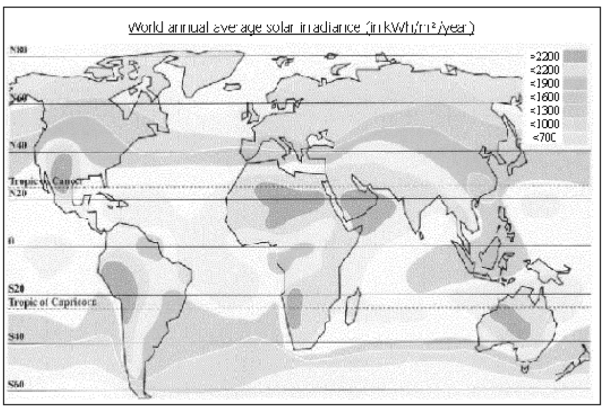
The electricity generated by the panels is stored in rechargeable batteries in order to power household appliances during the night.

Now most systems are grid-connected, often installed on private roofs and made up of few panels. There are some larger PV power plants (for example: the 10-MW “Bavaria solar park” in Germany). With private grid-connected systems, the electricity produced during the day is either used by the owner, or re-directed to the grid and purchased by a utility. Then, at night or on dark days when the PV panels do not produce sufficient power, electricity can be bought in from the grid.

2.2 PV energy: how many kWh every day

PV energy depends on the energy delivered by the sun, and thus on the day and time. At high noon on a cloudless day at the equator, the sun delivers about 1 kW/m² to the Earth’s surface. Nevertheless, this measure has to be corrected when accounting for clouds, latitudes and sunsets, Solar power is characterised by the solar irradiance, which is the average number of kWh per m² per year (or day). Typical irradiance ranges from 700 kWh/m²/year in northern regions (northen Europe, Canada) to 2200 kWh/m²/year in the sunniest areas (Africa, southern Europe).

Moreover, PV cells cannot fully convert sun power: typical solar panels have an average yield of 12%, with the best available panels at about 20%. Consequently, a production of about 1 kWh per m² PV panel on average can be expected every day in a good area after taking into account weather, latitude and yield.



2.3 Crystalline silicon dominates markets

There are several kinds of PV cells. The general principle is practically identical but semi-conducting materials differ. In 2005, mono and poly-crystalline silicon technologies dominated the market with 90.6% of the production. This domination can be explained by the fact that the manufacturers were more familiar with these technologies compared to others. Thin-film technologies share the remainder (9.4%). If these technologies have been slowing down since the early 2000s, they regained their dynamism in 2005. Actually, there is currently a relative shortage of PV-quality silicon. In the past, PV manufacturers used computing silicon rejections or surplus but now these sources are not sufficient. As thin-film technologies need much less silicon (amorphous silicon cells) or other semi-conducting materials (mainly CdTe and CIS cells), an expansion of the thin-film market can be expected.

2.4 Major manufacturers

In 2005, the global PV cell production reached 1818 MWp, i.e. 45% more than in 2004 (1256 MWp). Major PV cell manufacturers are Japanese and European and represent 73% of the world-wide production with 1339 MWp. The United States is the third largest producer but their market share is decreasing.

The most outstanding fact is the Chinese boom, with a cell production of 150 MWp in 2005, three times more than in 2004. China will probably become the third largest producer in 2006, leaving the United States behind.

This production comes from a relatively small number of manufacturers: the 20 largest producers represent 86% of the world-wide PV cell production.

Japan is the leader: Sharp the number 1 company producing 427.5 MWp in 2005, 23.5% of the market. Kyocera 7.8%, Sanyo 6.9%, and Mitsubishi Electric 5.5%, are in the top five and assure Japanese predominance in this sector.

There is one German manufacturer in the top 5: Q-Cells takes 2nd place with 9.1% of the market. This is the only German manufacturer in the top ten although the German market is the largest in the world. This paradox can be explained by the competitive strength of the Japanese PV industry.

Asian, especially Chinese producers have achieved considerable development for the past three years: The Taiwanese Motech (3.3%) almost doubled its production with 60 MWp in 2005 while the Chinese Suntech produced 4.5% of the PV cells with 82.5 MWp. Other Chinese producers emerged in 2005: Ningbo Solar, Shenzhen Topray and CEEG Nanjing. The Chinese PV industry can expect good prospects.

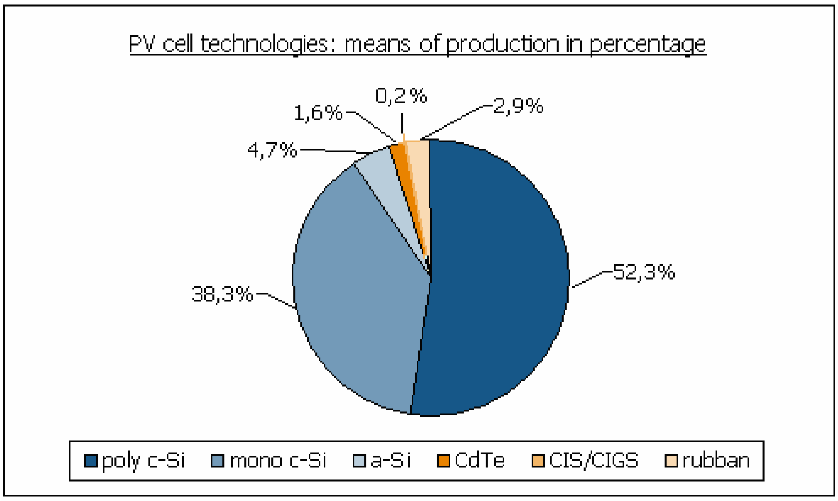


Figure 2-1
Means of Production

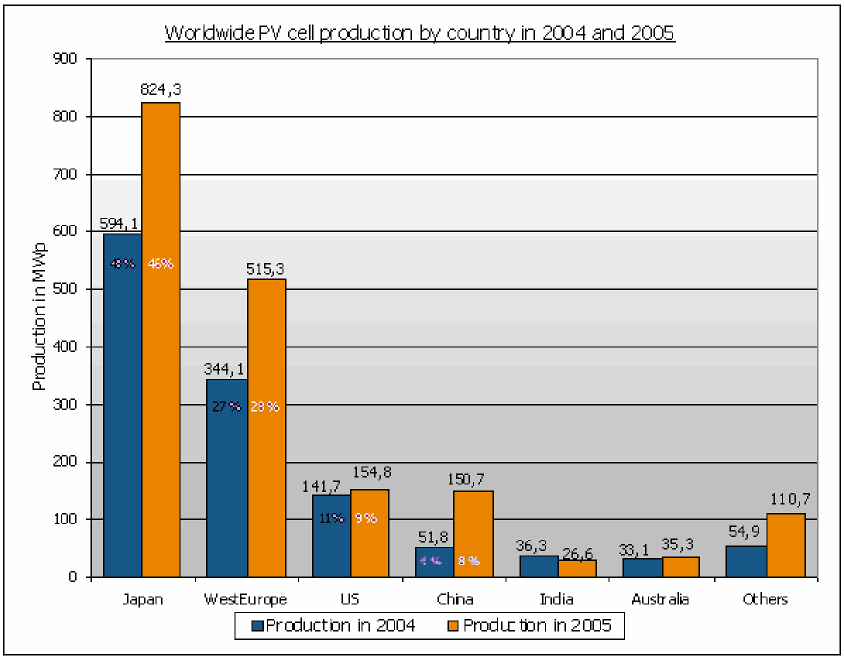
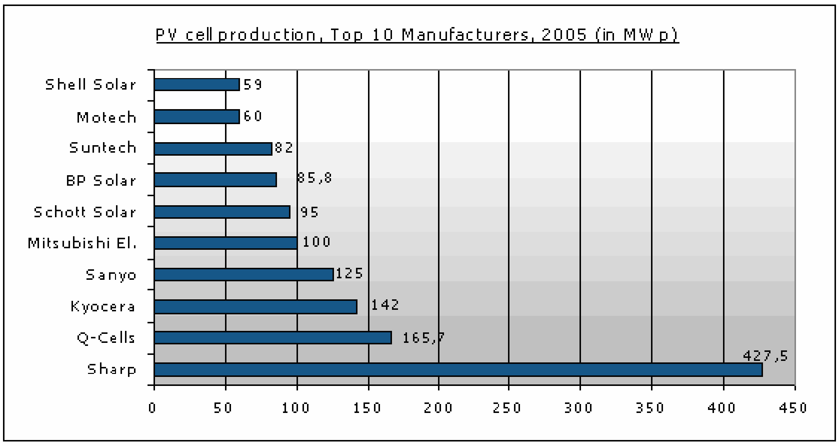


Figure 2-2
Worldwide Cell Production



Source: Photonnes International

Figure 2-3
PV Manufacturers

3. Why Use PV Systems?

3.1 PV energy assets

PV energy is a part of renewable energies system, and even if it is not as clean as one might think, it has nevertheless many advantages:

- Very reliable:
- No moving parts during operation
- Yield almost constant during 20 years
- Easily adjustable:
- Quick installation and dismantling
- Can be tailored for power from mW to MW
- A clean and affordable solution for remote areas
- Can be used in densely populated areas
- Environmentally friendly :
- No waste during operation
- No GHG or other gaseous emissions during operation
- Supportive of energy independence:
- PV energy is local
- Light is fuel free, no fuel need during operation
- Noiseless during operation

3.1.1 GHG emissions reduction and other environmental advantages

PV systems produce no polluting gases or wastes during operation. Nevertheless a considerable amount of energy is required for manufacture resulting in emissions. The average emissions during the life cycle are estimated between 60 and 150g CO2 per kWh produced by the PV system depending on the manufacturing country. This figure can be compared with other energy sources: between 800 and 1050g CO2/kWh for coal power plants, depending on the technology, 430g CO2/kWh for gas power plants, 6g CO2/kWh for nuclear power plants (average values).

A PV system of 1 kW (about 10 m^2 of PV cells) saves almost 2 tonnes of CO2 every year and much more in a country where most power plants use fossil fuelled. PV energy is clean compared with fossil fuels and can provide a solution for GHG emission reduction and climate change.

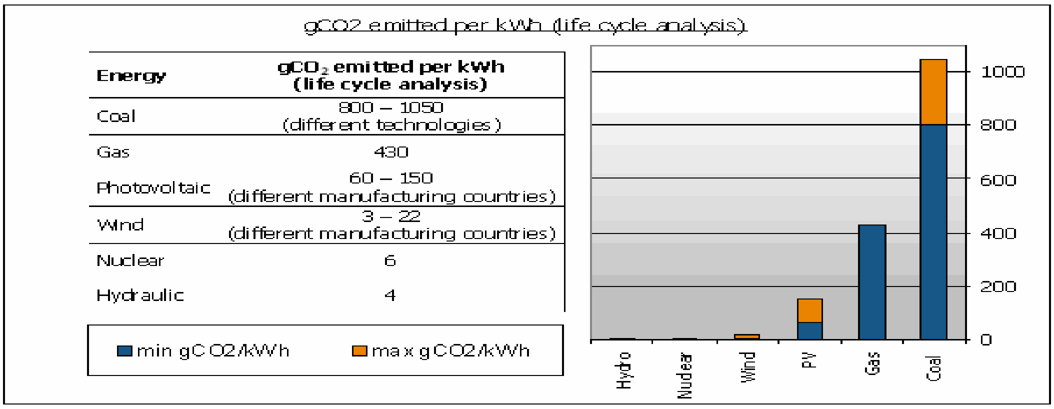
Moreover a PV panel produces electricity without any moving parts. PV plants are very reliable (between 20 and 25 years with a low-cost maintenance) and also totally noiseless. PV systems can be installed on roofs or walls in densely populated areas without causing noise pollution or significant visual interference.

3.1.2 PV panels are adjustable

PV systems can be rapidly and easily installed or dismantled when compared with nuclear, coal or gas power plants, and can respond to urgent demands when installed in the demand areas.

Figure 3-1

CO2 Emissions



gCO2 emitted per kWh (life cycle analysis)

Energy	gCO_2 emitted per kWh (life cycle analysis)
Coal	800 – 1050 (different technologies)
Gas	430
Photovoltaic	60 – 150 (different manufacturing countries)
Wind	3 – 22 (different manufacturing countries)
Nuclear	6
Hydraulic	4

Source: Jancovici

Dimensioning is simple. A PV panel may be described as a kind of brick, which can be assembled with other bricks to build a tailored power-system.

Because PV panels can be installed on roofs or walls in urban or remote areas, Since the land required is not a problem. Besides the land required is relatively small when compared with some other renewable energies.

3.1.3 PV systems can help to build energy independence

PV energy involves neither import dependence nor fuel price risk since there are no resource constraints, sunlight is free and available everywhere. Thus it can help to develop energy independence and, produced locally, can drive the local development: PV energy can provide long-term local employment and a source of income.

PV energy has many interesting features but since there is no light during the night, PV systems cannot supply a permanent flow of energy. The intermittence is a major drawback.

3.2 PV energy drawbacks

PV energy seems to be an ideal solution for providing alternative electricity supply but has several major drawbacks:

- Intermittence
- Grid connection
- Weather dependence
- Use of toxic materials

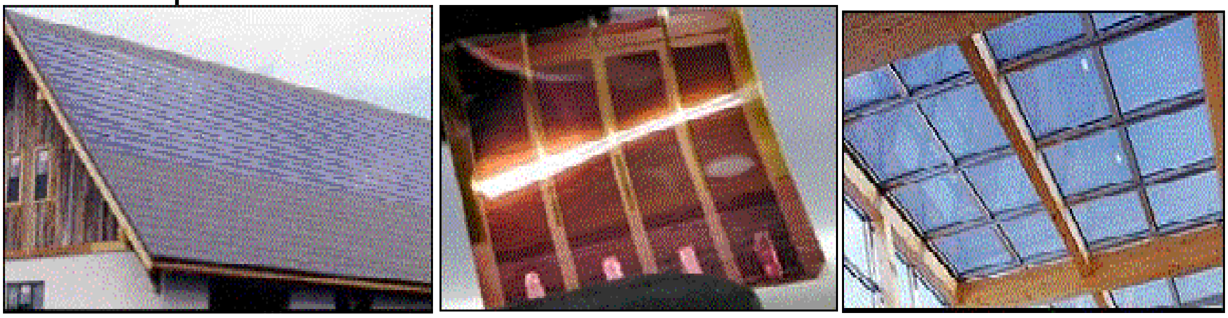
3.2.1 Intermittence

A PV system generates electricity only during the day and reaches maximum efficiency only when there is sufficient sunlight. Over the remaining time, PV energy must be substituted by another accessible energy source which can quickly be brought online, or by stored energy which increases the total cost.

Storage can be chemical (batteries) or physical (hydro) but conversion yields are low and storage capacities are relatively limited. Besides, battery manufacturing requires significant quantities of electricity and emits GHGs.

In addition, instantly available energy sources such as fossil fuel power plants have huge GHG emissions and hydro power plants have limited capacities. Nuclear power plants cannot be readily shutdown or restarted and cannot backup PV systems.

Figure 3-1
PV Use Examples



PV energy can play a significant role in countries where most power plants are fossil fuelled but cannot completely replace these plants

3.2.2 Grid connection

PV systems are small, numerous, and spread over a territory. As solar insolation varies, energy production is intermittent and grids need to be strengthened and extended to accommodate PV energy.

3.2.3 Sunlight and clouds forecasting

PV systems performance depends on the weather and on an accurate forecast of sunlight and cloud conditions is fundamental for efficient and economically viable use of this energy. While it may be easier to forecast sunlight than wind conditions, this is currently not sufficiently accurate and hampers attempts at optimal grid management.

3.2.4 Use of toxic and high-tech materials

The manufacture, use and disposal of PV systems pose risks as most systems involve the use of toxic materials for cells and batteries. These materials must be recycled or disposed of after the expiry of cells and batteries (Cd, etc.). Most PV cells require high-tech materials which are often composed of rare and expensive elements, which is partly why PV energy costs are still high.

PV energy has rather important drawbacks but these can be remedied: the PV energy R&D sector is active and expanding. In order to guarantee positive outlooks for PV energy production it is essential that improvements be made in solar forecasting, grid connection and the manufacture of cells (using new materials and processes).

4. R&D Breakthroughs are Expected

PV energy is not a novelty and fresh improvements emerge daily. Different technologies exist and many new solutions should quickly arise. Today is the first step and technological explosions are expected to shape an active PV R&D sector. Some developments and new technologies research are summarised as follow:

4.1 Optimising current technologies and reducing costs

- Crystalline silicon:
- High-efficiency cells
- Ultra-thin wafer slicing technology
- High quality ingot production
- Long-life modules
- Thin-film technologies:
- Low-cost process for CIS cells
- New wide-gap materials
- PV panels recycling
- Integrated systems

4.2 Developing innovative technologies

- New solar cells:
- Organic solar cells
- Dye-sensitised solar cells
- Multi-junction solar cells
- Silicon nanostructures
- Ultra high-efficiency solar cells with concentrator systems
- New manufacturing processes

4.3 Increasing the value of useful PV energy

- Improving sunlight forecasts
- Improving grid connection
- Developing modelling tools (adaptation to weather conditions)
- Optimising and developing new energy storage systems

4.4 Finding new utilisations

- Transparent cells for greenhouses
- Flexible cells
- Ultra light cells
- Bifacial cells
- Hybrid (hydrogen, fuel) systems

This list is not exhaustive, since PV energy R&D is booming and prolific. Therefore PV energy also often takes advantage of technological innovations in the electronic and materials sectors.

So PV energy R&D should enjoy good prospects and improve the power production quality of PV and reduce costs. PV solar energy can therefore supply clean and competitive electricity production throughout the world.

5. Expense and Viability in Remote Areas

The following cost statement does not claim to be exhaustive. PV energy cost depends on the country of installation, manufacturing cost, system size and other factors. The costs detailed below are averages of European grid-connected installations and must be viewed in order of magnitude.

5.1 Investment costs

The initial investment comprises the project study and management, the purchase of the PV panels, inverters and electric cables, the cost of the PV panel support structure, the installation and start-up costs. Dismantling costs are not considered here since they are negligible when compared to fossil or nuclear energies despite the fact that PV panels contain toxic materials.

In 2005 this initial investment represented between 4 and 9 € per Wp in Europe for grid-connected PV roofs. This cost has regularly decreased over the past years and should yet impressively decrease in the future, owing to market expansion and technological expansion.

The following diagram shows the cost structuring for the installation of a PV system of 1 to 5 kWp installed on a roof or fronted in 2003:

Stand-alone PV systems are until 3 times more expensive but cost is extensively dependent on usage and climate. This difference essentially arises from the need for storage capacity during the night. However, stand-alone systems in remote areas are often competitive when compared to a necessary grid extension. These extensions are very expensive, costing between 20,000 and 30,000 € per km in European countries. Stand-alone systems are consequently often financially viable in remote areas.

5.2 O&M costs

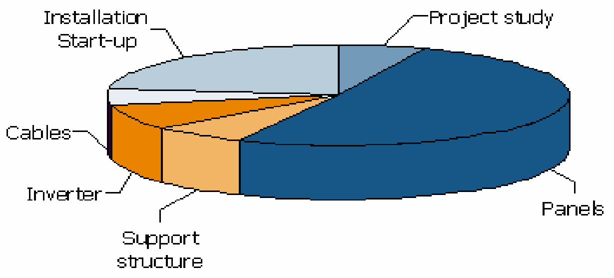
PV panels are designed to have a lifetime of about 20 years. As there is no movement, panels are very reliable making O&M costs very low. These correspond essentially to the cost of new inverters and batteries. For a grid-connected system, these O&M costs represent about 1% of the investment. PV systems therefore achieve a very good availability of around 95 to 100%.

Consequently, with O&M costs representing only 1% of the initial investment, PV energy differs from other energies such as coal or gas, for which the fuels only correspond to 40 to 60% of the total cost.

Figure 5-1
Investment Cost

Investment Costs (in %)

Element	Cost
Project study	6 %
Panels	51 %
Support structure	7 %
Inverter	8 %
Cables	5 %
Installation/start-up	23 %



Source: IEA

5.3 Production costs

In Europe, one kWh produced by a PV solar system costs between 25 and 65 c€, depending on the type of system (large commercial power plant or private system) and locality. As it is much more expensive than a “standard” kWh, the cost of back up capacity should be considered since sunlight is an intermittent resource. Coal, gas and nuclear electricity cost indeed between 3 and 6 c€/kWh.

Nevertheless, external costs (impacts on human health, ecosystems and global warming) are not considered here, although they can be estimated as very low for PV energy compared to coal and gas: Given these conditions, PV energy is not yet very attractive, in terms of cost, for grid-connected systems and cannot compete with other usual energies without incentives, but costs should effectively decrease in the future, and PV energy provide an attractive source within the next decades.

6. Encouraging PV Development

6.1 General statement

Renewable energies are essential for drastic reduction in GHG emissions without decreasing our electricity production. Unfortunately they are generally more expensive than regularly produced energies and must consequently be supported by incentives and positive energy policies.

Before detailing the different incentive systems, let us note that a massive resort to renewable energies may also demand radical change in the population mindset. Citizens must play their part in changing the energy landscape. This is the reason for some countries to include public awareness campaigns and other events within an energy policy.

Similarly, as renewable energy technologies are often relatively recent, countries sometimes choose to support research and development in this field. Nevertheless, even if those measures bear fruit, in the long run they are insufficient and must be combined with regulations and incentives for the energy utilities.

6.2 Main incentive systems (Source: ECN)

In general there are two different means of support: the authorities can either compel the utilities to produce electricity from renewable energy sources (quota obligations with penalties, fossil fuel taxes) or financially support renewable energy uses (capital grants, tax credits, guaranteed prices).

6.2.1 Quota obligations and renewable energy targets

A growing number of countries currently have renewable energy targets (see the complete list in Annex 2). Such obligation schemes aim to increase demand with a percentage or amount of electricity supply to be generated from renewable energy by 2010, 2020 or 2030. E.g. the European Union aims at achieving 21% electrical output from renewable energy sources by 2010, and Australia an annual increase of 9,500 by 2010. Quota obligations involve penalty systems compelling electricity utilities or authorities to stand by their commitments.

Obligation systems are often related to “Tradable Renewable Energy Certificates” which provide compliance flexibility. These certificates, which correspond to the value of electricity produced from renewable energy, can be detached from the sale of the physical electricity and so traded in order to be in compliance.

If renewable energy targets are relatively common, penalty systems (where they exist) are often not suppressive enough to be particularly efficient.

Therefore many governments support renewable energy development with other systems.

6.2.2 Feed-in / Guaranteed Prices

Under the feed-in system, the government sets the price of electricity produced by renewable energies and the utilities are obliged to purchase this at a set price. Production costs depend on the energy, so the guaranteed price differs depending on technologies. This tariff is valuable for a given period of time and may decrease in due course.

For instance, in Germany, for a roof system of less than 30 kWp, electricity is purchased 57.4 c€/kWh in a period of 20 years. In Spain, an installation of less than 100 kWp, the guaranteed price stands at 575% of the "standard" electricity price over 25 years.

Feed-in systems have principally supported renewable energy development in the European Union, especially in Denmark, then in Germany and Spain and are frequently chosen throughout the world.

If the set price is substantially high, this system can lead to sustained and significant growth, as in Germany or in Spain. However, and this is the main criticism, an overly high set price may give rise to excess profits at the expense of consumers.

6.2.3 Bidding systems

A bidding (or tendering) system corresponds to a government-administered competitive bidding process whereby renewable energy developers compete for access to power purchase agreements and/or to a government-administered fund. Contracts are then signed for the most competitive bids and the utilities are often obliged to purchase electricity at the price proposed under the winning bids. There are therefore invitations to tender for different renewable energy technologies. The USA, China, France, the UK have used such systems.

Such bidding systems result in cost efficiency and price reduction due to competition between developers, but have not yet been totally satisfactory in comparison to feed-in systems, possibly because of overly complex procedures or the intermittence of invitations to tender.

6.2.4 Capital grants and other financial subsidies

Solar energy power plants need important initial investment and on the whole have low O&M costs. Consequently governments often apply financial incentives in the shape of grants as a percentage of total investment or €/kW grants.

Investment grants have been a common type of support for some years, probably because this support instrument is easy to administer.

Nevertheless plant owners are not encouraged to operate the plants as efficiently as might be the case for production-based financial supports which is the reason for some countries starting to offer financial subsidies on a production basis.

6.2.5 Tax credits

In order to develop renewable energies, many countries apply tax incentives: tax refunds for renewable electricity, exemption from investments in renewable power plants from income or corporate taxes, exemption of renewable energy from energy taxes.

Such incentives can relate to investment or production, they improve competition for these energies and are easily established and adjusted by the authorities according to circumstances.

6.2.6 Green marketing

Green marketing is not really an incentive because it depends only on consumers' volition: consumers pay voluntarily electricity at a premium to be supplied by renewable electricity only. This premium represents the additional generation cost of such electricity. In this system public awareness and willingness are obviously the crucial factors. For the time being green marketing has not yet generally succeeded in producing a large demand for renewable electricity.

7. Sunny Future for PV Power

7.1 Long-range PV potential

Theoretically solar energy has enormous potential. The total amount of solar energy reaching the Earth's surface is a thousand times greater than the world total energy consumption. This energy is not totally retrievable but the technical potential for converting solar energy directly into heat or electricity is huge and expected to be more than 440,000 TWh/year, i.e. about three or four times the present total energy consumption of the world.

The long-range solar electricity production potential (corresponding to a reasonable required area) is estimated at 4,400 TWh per year, i.e. more than 26% of the world-wide electricity production in 2003 (16,570 TWh). This is lower than for biomass (11,000 TWh) and hydro (7,500 TWh) energy potentials, but almost identical to the wind energy potential (around 4,500 TWh).However, if 57% of the hydro potential is already currently exploited, PV energy is barely exploited at present: only 2 or 3 TWh produced globally in 2005. Consequently we can expect very high growth in the PV energy sector over many years, all the more as PV energy has many interesting assets:

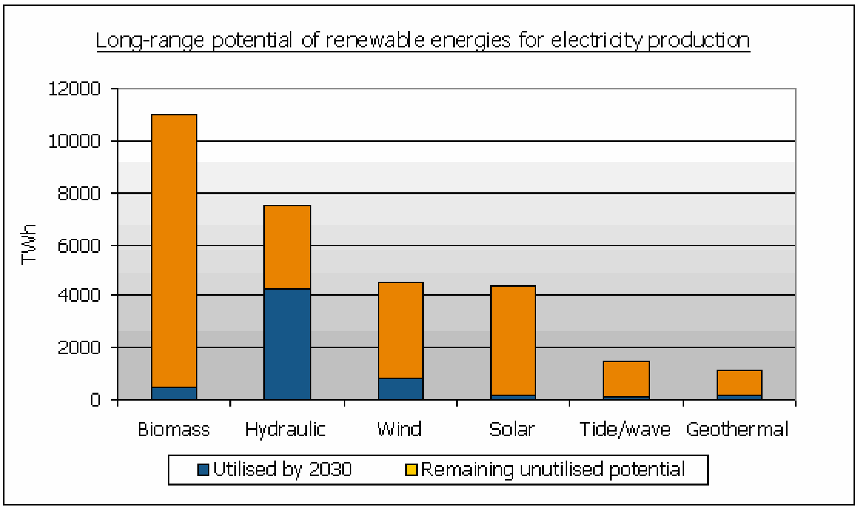
- PV technology is already reliable showing relatively good performances and Investment costs are currently high but should be divided by three by 2020 thanks to thin-film cells and the market extension
- PV system international norms are a guarantee of reliability, productivity and security for installation financing

7.2 Capacity and production forecasting

If we exclude hydro and biomass energy, wind and PV solar energies will probably be the major renewable energies in the next decades. A European Commission study in PV-TRAC is optimistic that these systems will supply 4% of the world-wide electricity in 2030 with an installed capacity reaching 1,000 GWp with 200 GWp in Europe included. However, the European Photovoltaic Industry Association (EPIA) has more moderate aspirations and plans a capacity of only 140 GWp by 2030 throughout the world.

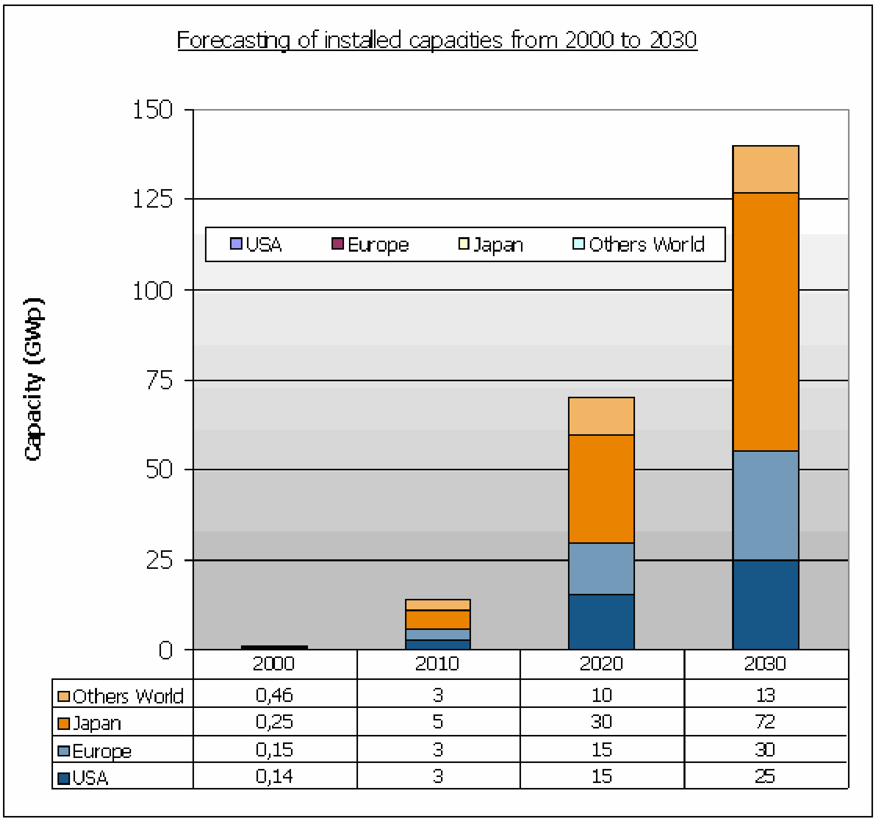
Although sunlight reaches all countries, with greater sun irradiance in most developing countries, PV energy development will probably not be international. As this technology will yet remain expensive, PV energy will mostly be used in developed countries. Though stand-alone PV systems would be a suitable solution to supply electricity in remote areas in countries where grids are still scaled-down. However, without aid, PV energy cannot achieve a sufficient level of development in countries where it would be most efficient.

With a capacity of 140GWp throughout the world in 2030, PV sector would save about 85 Mtonnes of CO2 per year. However solar systems would be installed mostly in Japan, Europe and USA (90%) and PV energy only represent 0.5% of the total production. The GHG emission reduction would be still insufficient: PV solar energy must be a part of an energy mix.



Source: IEA

Figure 7-1
Renewable Potential



	2000	2010	2020	2030
Others World	0,46	3	10	13
Japan	0,25	5	30	72
Europe	0,15	3	15	30
USA	0,14	3	15	25

Source: EPIA

Figure 7-2
Capacities Forecasting

8. Conclusions

PV energy has certainly important potential throughout the world and will enjoy a significant development in coming decades, all the more as technical improvements and cost reductions should be numerous.

Developed countries and probably China will significantly increase their installed capacity. Pioneer countries in this field, Japan and Germany, are also the most active in R&D and will preserve this advantage for many years. PV energy could be a really suitable solution for developing countries that have much sunlight, but unfortunately on their own will probably not be able to support development in remote areas.

Technically, ruptures are expected and costs must surely drastically decrease due to important R&D efforts and widened production. Ultimately, PV energy needs strong incentive mechanisms in order to accelerate in this sector, find new markets and encourage technical improvements.

This clean energy is currently expensive. However, it will certainly be beneficial and can play a sizeable role in GHG emission reduction. Nevertheless, owing to intermittence and limited potential, PV energy alone will be unable to supply the entire electricity demand.

A relatively clean energy mix, combining renewable energies (wind, solar, biomass, geothermal and marine energies) with nuclear, hydro and others (depending on local and regional capacities), is absolutely necessary to guarantee sufficient electricity production and significantly reduce GHG emissions.

Appendix D

Bibliography

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Section 3
Biomass Electricity Today

1. Biomass: 2nd Largest Renewable Sector

Biomass is a renewable source of energy. It includes various organic materials, such as wood by-products and agricultural wastes, which can be used to produce energy. (See detailed definition § 2.1. What is biomass?)

1.1 Current trends

Long-neglected in favour of fossil fuels, biomass has again been in vogue for some years. It is can substitute some fossil fuels for the chemical industry and energy (biofuels for transport, heat and electricity). Electricity from biomass, that we shall call bioelectricity, has enjoyed constant development. Due to co-generation, a unique biomass plant can also provide heat and electricity at the same time.

In 1998, 98.8 TWh were produced from biomass throughout the world. In 2005, the world electricity production from biomass reached 183.4TWh. Growth is limited but continuous and prospects are positive.

Due to this development, biomass was the second largest renewable sector with 5.6% of the renewable origin electricity total in 2005, behind hydro power (89.5%) but ahead of wind energy (3.0%). However, biomass actually delivered only 1% of the global electricity, far behind fossil fuels (66.4%), large hydro (16.2%), and nuclear (15.2%).

1.2 A market focused on few countries

Quite obviously, biomass is often used as a combustible in areas where forests are predominant. However, for most of the time heating and cooking are the two firsts for biomass.

Consequently, biomass power plants are quite rare in comparison with the abundance of the resource and so mostly installed in forest cover and developed areas, where the electricity demand is larger.

Europe and North America are thereby the two unmistakable leaders with almost 75% of the global bioelectricity production in front of Asia (about 18%), while Africa represents only 0.2% of these 164.2 TWh.

The top bioelectricity producing countries of this is revealing: the United States of America, the largest electricity consumer, is leader with 56.3 TWh, i.e. almost one third of the world-wide production. Then come Germany and Brazil with 13.4 TWh, followed by Japan, Finland, the UK, Canada and Spain.

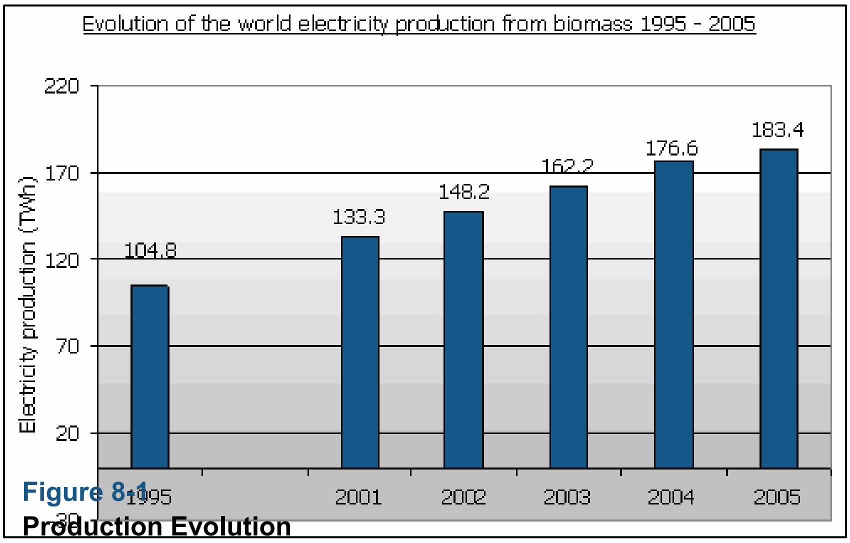


Figure 8-1
Production Evolution

Bioelectricity production per continent in 2005

Country	Production (TWh)
North America	64.7
Europe	71.9
S/Central America	24.2
Asia	19.8
Oceania	1.7
Africa	1.1

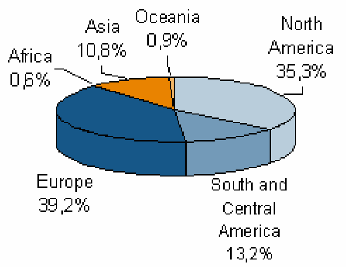


Figure 8-2
Production per Continent

Source: Observ'ER 2005

Bioelectricity production, Main Countries, 2005

Country	Production (TWh)
USA	56.3
Germany	13.4
Brazil	13.4
Japan	9.4
Finland	8.9
UK	8.5
Canada	8.5
Spain	7.8

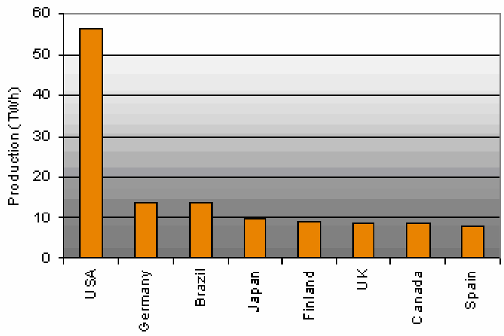


Figure 8-3
Bioelectric Production

Source: Observ'ER 2006

2. Multiple Technologies

2.1 What is biomass?

2.1.1 Our definition

Biomass is a highly complex source of energy and has some important identifying features when compared to conventional energy sources.

Firstly, there are differing definitions of biomass. A dictionary would give this definition: “biomass is all of the living material in a given area”. In the energy field, many people add to this: “living material residues of wastewater treatment plants and domestic wastes”. In this instance we will restrict the definition of biomass to “non-contaminated vegetal by-products”, in other words:

- Wood and wood wastes
- Vegetal agricultural crops and wastes
- Vegetal forest residues

2.1.2 Biomass composition

Biomass is an organic material composed of carbon (C), oxygen (O), hydrogen (H) and nitrogen (N), to which we must add mineral matter that constitutes ashes. If percentages of C, O, H, N are relatively constant, ash composition and quantity can strongly vary. Therefore agricultural and herbaceous by-products have a high rate of ash compared to wood.

These variations constitute a problem for the power plant conception. Any difference in the C, O, H, N proportions changes the calorific power of the combustible. Moreover, nitrogen can produce NOx in the smoke and ashes. These contain minerals that can be volatile and dangerous if they escape from the power plant with the smoke.

Furthermore, as a living material, biomass contains water. Moisture depends on time and the species. Just after their harvest, non-woody biomass can have a moisture rate of 95%. This moisture poses several disadvantages:

- From 60%, biomass combustibility is almost nil. Drying is indispensable.
- Moisture reduces the efficiency of thermal reaction.
- Moisture increases the biomass weight and consequently the carriage costs.

Finally, biomass is rarely homogeneous. However, a biomass power plant needs a combustible with stable features. This is why conditioning is necessary. In order to produce bioelectricity, one typically needs drying systems in order to reduce and homogenise moisture, and grinding systems to homogenise granulometry.

Figure 2-1
Biomass Characteristics

Biomass type	% of the total organic fraction				% of the dry matter
	C	H	O	N	Mineral matters (ash)
Broad-leaved	51	6.07	42.5	0.37	2.5
Resiniferous	50.8	6.06	42.7	0.36	2.3
Straw	48.9	5.97	43.9	0.82	7.3
Rice hull	48.2	6.48	45.1	1.19	15.8
Bagasse	53.1	6.03	38.7	1.25	9.3

Source : ECN

Source: ECN

2.2 How is electricity produced from biomass?

Wood and other biomass materials can be transformed and used in order to generate energy. There are three major transformations presently in use: combustion, gasification and pyrolysis of biomass.

Combustion is the most common way of converting solid biomass fuels to energy because of the low cost and high reliability. Gasification and pyrolysis are under development but should enjoy a rosy future. Biomass can also substitute a fraction of coal in coal-fired boilers: co-firing is another solution.

2.2.1 Combustion

Combustion is well understood, relatively straightforward and commercially available. It is a proven technology. During combustion, the biomass first loses moisture at temperatures up to 100°C, using heat from other particles that release their heat value. As the dried particle heats up, volatile gases containing hydrocarbons, CO, CH_4 and other gaseous components are released. In a combustion process, these gases contribute about 70% of the heating value of the biomass. Finally, char oxidises and ash remains. Combustion provides heat, which will be used for heating or steam production in order to generate electricity.

A combustion installation needs to be properly designed for a specific fuel type in order to guarantee adequate combustion quality and low emissions.

2.2.2 Pyrolysis

Pyrolysis is a thermal transformation in inert atmosphere. Biomass is thereby broken up into a solid fraction, liquids and gases. Proportions of these products depend on temperature, pressure, heating speed.

The solid fraction can be used in boilers to produce electricity. Liquids can be used in motors to generate electricity or after refining, for transportation. Gases can be burnt to continue the solid or liquid process.

2.2.3 Gasification

Gasification consists of breaking up the biomass in a reactive atmosphere (air, O_2, CO_2, H_2O…) in order to produce gases. These gases are mainly H_2, CO, CO_2 and CH_4 which can then be burnt to produce heat or used in motors and turbines to produce electricity. They can also be used to produce chemicals or transportation fuels.

The table below shows the conditions of temperature, atmosphere, and the products for these three transformations.

2.2.4 Co-combustion

Essentially one can distinguish three different concepts for co-firing biomass in coal boilers, all of which have already been implemented either in a demonstration or a fully commercial basis:

Figure 2-2
Biomass Processes

Transformation	Temperature	Atmosphere	Products
Combustion	> 900°C	O_2 (air)	CO_2 + H_2O
Pyrolysis	< 700°C	Inert (without O_2)	Solid (char) + liquid (bio-oil) + gas
Gasification	> 800°C	Reactive gas (air, O_2…)	Gaseous mix (H_2, CO, CO_2, CH_4)

Source:

- Direct co-firing: it is the most straightforward and commonly applied and low-cost of all. Biomass fuel and coal are burnt together in the same furnace.
- Indirect co-firing: a biomass gasifier can be used to convert solid biomass raw materials into fuel gas form, which can be burnt in the same furnace as coal. This offers the advantages that a wider range of use of biomass fuels and that the fuel gas can eventually be cleaned and filtered to remove impurities before burning.
- Separate biomass boiler: it is installed in order to increase the steam parameters in the coal power plant steam system.

Co-firing biomass with coal in traditional coal-fired boilers is becoming increasingly popular because it is a way to improve existing coal power plants. It is indeed an economic means of using biomass, as no major modification to the coal plant is necessary and no new biomass plant needs to be built. However, biomass can substitute only 10% (in power) of coal.

Compared to coal, biomass can be less costly and reduce SO2, NOx and other GHG emissions while biomass conversion to electricity through co-firing almost achieves the same level of efficiency as in a coal-powered plant.

3. Why Biomass Power Plants?

3.1 Biomass assets

Biomass energy forms part of the renewable energies while harvested areas are replanted, and offers an array of benefits:

- No greenhouse gas during the life cycle and less emissions than fossil-fuel plants
- Forest sustainability
- Helpful to develop energy independence and regional economy
- Proven technologies for combustion and co-firing
- Use of low-cost products

3.1.1 Greenhouse gas emission reduction

The CO2 that was absorbed as the plants grew returns to the atmosphere as biomass burns. On a net basis, CO2 from biomass is lower than from a fossil plant. Nevertheless, there are emissions associated with the harvesting, processing, transportation and combustion operations, which are part of the biomass utilisation cycle.

We can estimate these emissions with as average during the life cycle: between 17 and 27g CO2 per kWh produced by the biomass power plant when biomass is managed in a sustainable cycle (energy crops, replanting harvested areas). Biopower can be considered a “carbon-neutral” power generation option. These figures must be compared with other energy sources: between 800 and 1050g CO2/kWh for a coal power plant (depending on the technology), 430g CO2/kWh for gas power plants, 6 TO 9g CO2/kWh for nuclear power plants (average values). Roughly speaking, 1 tonne of wood saves the emission of about 1 tonne of fossil fuel CO2. Consequently, biopower is a clean energy compared to fossil fuels and can be a solution to reduce GHG emissions and limit climate change.

In addition, biomass resources generally produce fewer emissions than fossil fuels. Biomass contains less sulphur than coal and therefore produces less SO2 and emissions of NOx are also usually lower. However, less regulated, small-capacity installations often suffer from poor environmental performance.

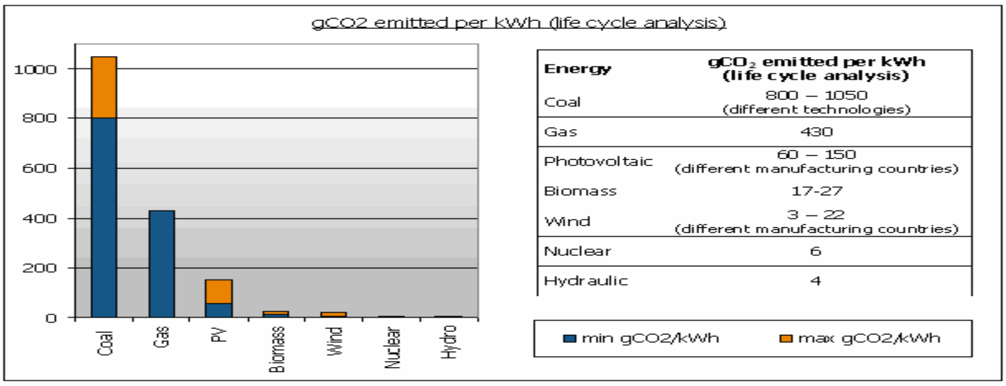
3.1.2 Forest sustainability

Biomass systems are most often fuelled by waste wood, from logging operations, forest thinning, low-grade wood or sawmill residues, which are far too frequently burnt in the open without pollution control. These systems create a commercial market for wood whose extraction benefits forest health, while also boosting the forest-product economy. Rather than depleting the forest resource, biomass energy, when sustainably supplied, aids growth.

Moreover, providing biomass can reduce the risk of wildfire by removing small diameter trees that act as a fuel. It prevents harmful effects of forest fires on the atmosphere: forest fires release mercury, toxic materials, GHGs and NOx.

Figure 3-1

C02 Emissions



Energy	gCO_2 emitted per kWh (life cycle analysis)
Coal	800 – 1050 (different technologies)
Gas	430
Photovoltaic	60 – 150 (different manufacturing countries)
Biomass	17-27
Wind	3 – 22 (different manufacturing countries)
Nuclear	6
Hydraulic	4

Source: Jancovici, WEC, EDF

3.1.3 Biomass can help to build energy independence

Biomass is locally produced, commonly available throughout the world and involves comparably low import dependence and less fuel price risk since resources are local (pricing of biomass fuel is relatively stable).

Thus it can help to build energy independence and, as a local energy, can be a vector for local development: biomass can support businesses in the forest-products sector and provide long-term regional employment and source of income.

3.2 Biomass drawbacks

Biomass conversion to electricity seems to be faultless nevertheless there can be several major drawbacks:

- Seasonal availability
- Transport and conditioning
- Polluting emissions
- Required land area

3.2.1 Seasonal availability

Availability of agricultural residues is seasonal and restricted to a few months. These agricultural by-products must be harvested and stocked if possible. In some cases storage is impossible due to the risk of fungi development, so availability can be a delicate issue and cause very high storage costs. Biomass must often be substituted by another energy source for part of the year.

This problem exists for vegetal forest residues, wood and wood wastes, but to a lesser extent and productivity does not depend on the vagaries of weather, as do agricultural crops.

In a nutshell, biomass can play a significant role but cannot totally replace other sources of energy.

3.2.2 Transportation and conditioning

We previously noted that biomass conditioning is fundamental, as biomass is rarely homogeneous while a biomass power plant needs a combustible with stable features. Drying systems to reduce and homogenise moisture and grinding systems to homogenise granulometry are often necessary.

Biomass must be transported from the harvest areas to the power plants. However, a biomass power plant needs between 15 and 60 tonnes of fuel per MW per day (range on different samples). As storage can be difficult, this operation can be daily and generate noise pollution along the route and close to the power plant. Transportation and conditioning of biomass are complex, demand important investment with high operation costs and affect the energy balance.

3.2.3 Polluting emissions

As noted previously, biomass contains nitrogen that can produce NOx in the smokes. Ashes also contain minerals, which can be volatile and dangerous if they escape from the power plant with the smoke. These materials, which can also impair

Figure 3-2
Biomass Operations

the power plant by corrosion, must be collected, recycled or disposed in order to avoid pollution.

In addition, carbon dioxide emissions are not insignificant: thermal transformation, harvesting, transportation and conditioning all generate carbon dioxide.

Bioelectricity is consequently not totally clean but can be much cleaner than electricity derived from coal, gas or oil.

3.2.4 Required land area

The land area that is required for exploitation by a biomass power plant is huge when compared to other energies. The following table shows this land area required for exploitation of a 1 GW renewable energy plant (average values)

Forests and crops need a very large area for growth and one can realise that transportation is a major issue for biomass exploitation.

Moreover, this land area must to be shared between biomass for alimentary and energy purposes together with habitation needs and one must reconcile these three needs.

So biomass power has important drawbacks but most of them can probably be remedied: the biopower R&D sector is very active and achieves real expansion. Improving conversion efficiencies, transportation and conditioning conditions and reducing polluting emissions are essential in order to guarantee that biopower makes a good prospect.

4. R&D Advancements in the Offing

4.1 Optimising combustion and reducing costs

- Increasing energy efficiency
- Improving multi-fuel systems
- Improving co-firing systems
- Developing systems for new fuels (energy crops, waste wood, agricultural residues)
- Encouraging and optimising combined heat and power systems
- Reducing atmospheric pollutants
- Increasing reliability and availability
- Reducing corrosion, agglomeration and other ash problems
- Developing modelling tools (adaptation to the plant size and the type of fuel)
- Developing tools focused on controlling and monitoring combustion

4.2 Developing innovative technologies

- Improving gasification systems:
- Developing reliable and cost effective gasification systems
- Cleaning gases in order to obtain gases of sufficient quality for more demanding final use
- Improving pyrolysis systems to get better quality bio-oils
- Developing anaerobic digestion:
- Monitoring and controlling digestion processes
- Cleaning gas which is produced

4.3 Improving biomass logistics

- Developing cost-effective integrated approaches for the biomass collection
- Developing cost-effective integrated approaches for the fuel preparation
- Developing cost-effective integrated approaches for the fuel storage
- Developing cost-effective integrated approaches for the biomass delivery

5. Biomass May Compete Financially

The present cost analysis does not claim to be exhaustive. Bioelectricity cost depends on the installation country, technology, power plant size, fuel price and other factors. The below-mentioned costs must be viewed in order of magnitude. They are cost ranges of combustion power plants throughout the world.

5.1 Fuel costs

Biomass comprises different vegetal by-products, whose costs may deeply differ, depending on local resources and transportation possibilities. Mill/wood wastes cost between 5 and 15 €/MWh and between 15 and 30 €/MWh for forest residues.

Furthermore, in the case for some wastes fuel cost can be insignificant when the power plant is built close to the waste production site and fuel can be free. Transportation generates very high operation costs.

Actually, these fuel costs are in the same order of magnitude as coal and gas, and are often lower: gas costs about 30 €/MWh and coal around 10 €/MWh.

With regard to co-firing, EPRI studies indicate that this can be economical if biomass fuel is delivered at a price 0.8-1.2 €/MWh below that of coal.

5.2 Investment, O&M and production costs

As costs depend deeply on the technology, the size, and if there is co-generation or not, we have realised a table with averages in these three cost categories. Operation and maintenance costs do not comprise fuel cost which can seriously affect the production cost as it is comprised between 0 €/MWh and 30 €/MWh PCI.

With a production cost between 40 and 110 €/MWh, biomass is almost competitive when compared to conventional energy sources, but often needs subsidies to be really competitive.

Coal, gas and nuclear electricity cost indeed between 30 and 60 €/MWh.

The investment costs also depend on the used biomass. For example, the investment costs of stand alone biomass plants fuelled by waste wood are up to 2500,- Euro/kW in Germany, and the investment costs of biomass co-combustion plants are 350,- Euro/kW. But these are the costs that must be paid in addition to the existing fossil-fired plant that is enabled for co-firing.

Table 5-1

Costs

Category	Euro/kW$_e$	
	Min Value	Max Value
Investment	1350	2200
O&M	25	50
Production	40	110

Source: EC ExternE 1999, IEA

Table 5-2

External Costs

Type of Plant	Cost (Euro/kW)	Cost (Euro/MWh)	
	Investment	Production	External
Nuclear	800-1600	25-30	2.3-18.8
Coal	800-1200	30-35	19-99
Gas	350-650	35-60	7-31
Large Hydraulic	~2000	30-65	0.04-6.03
Geothermal	1400-1700	50-80	0.2-0.5
Biomass	1350-2200	41-110	2.0-50
Wind (OS)	900-1300	50-120	0.5-2.6
PV grid-connect	4000-9000	250-650	1.4-3.3

Source: IEA

Nevertheless, external costs (taking into account impacts on human health, ecosystems, environment, global warming and amenity losses) are not considered in those figures. They can be very low for biomass (they depend on the country, the technology and the forest sustainability) and high for coal.

The following table shows these external costs but also investment and production costs for several energy sources in order to make the comparison possible:

In these conditions, biomass energy is attractive and can almost compete with other energies. Due to some incentives and regulations that will aid progression, biomass energy should be in vogue over the next decades.

6. Encouraging Biomass Energy Development

6.1 Sweeping statement

Renewable energies will be essential to dramatically reduce our greenhouse gas emissions without decreasing our electricity production. Unfortunately they are generally more expensive than usual energies. Consequently incentives and positive energy policies must support renewable energies.

Before detailing the different incentive systems, let us note that a massive resort to renewable energies may also demand radical changes in population mindsets. Citizens must play their part in changing the energy landscape. This is the reason why most countries include public awareness campaigns and other events within an energy policy.

Similarly, as renewable energy technologies are often relatively recent, countries sometimes choose to support research and development in this field.

Nevertheless, even if those measures bear fruit in the long term, they are insufficient and must be associated with regulations and incentives for the energy utilities.

6.2 Main incentive systems (Source: ECN)

In general there are two different means of support: the authorities can either compel the utilities to produce electricity from renewable energy sources (quota obligations with penalties, fossil fuel taxes…) or financially support renewable energy uses (capital grants, tax credits, guaranteed prices…).

6.2.1 Quota obligations and renewable energy targets

A growing number of countries currently have renewable energy targets (see the complete list in Annex2). Such obligation schemes aim to increase demand with a percentage or amount of electricity supply to be generated from renewable energy by 2010, 2020 or 2030. E.g. the European Union aims at achieving 21% electrical output from renewable energy sources by 2010, and Australia an annual increase of 9,500 by 2010. Quota obligations involve penalty systems compelling electricity utilities or authorities to stand by their commitments.

Obligation systems are often related to “Tradable Renewable Energy Certificates” which provide compliance flexibility. These certificates, which correspond to the value of electricity produced from renewable energy, can be detached from the sale of the physical electricity and so traded in order to be in compliance.

If renewable energy targets are relatively common, penalty systems (where they exist) are often not suppressive enough to be particularly efficient. Therefore many governments support renewable energy development with other systems.

6.2.2 Feed-in / Guaranteed Prices

Under the feed-in system, the government sets the price of electricity produced by renewable energies and the utilities are obliged to purchase this at a set price. Production costs depend on the energy, so the guaranteed price differs depending on technologies. This tariff is valuable for a given period of time and may decrease in due course.

For instance, in Germany, for a roof system of less than 30 kWp, electricity is purchased 57.4 c€/kWh in a period of 20 years. In Spain, an installation of less than 100 kWp, the guaranteed price stands at 575% of the "standard" electricity price over 25 years.

Feed-in systems have principally supported renewable energy development in the European Union, especially in Denmark, then in Germany and Spain and are frequently chosen throughout the world.

If the set price is substantially high, this system can lead to sustained and significant growth, as in Germany or in Spain. However, and this is the main criticism, an overly high set price may give rise to excess profits at the expense of consumers.

6.2.3 Bidding systems

A bidding (or tendering) system corresponds to a government-administered competitive bidding process whereby renewable energy developers compete for access to power purchase agreements and/or to a government-administered fund. Contracts are then signed for the most competitive bids and the utilities are often obliged to purchase electricity at the price proposed under the winning bids. There are therefore invitations to tender for different renewable energy technologies. The USA, China, France, the UK have used such systems.

Such bidding systems result in cost efficiency and price reduction due to competition between developers, but have not yet been totally satisfactory in comparison to feed-in systems, possibly because of overly complex procedures or the intermittence of invitations to tender.

6.2.4 Capital grants and other financial subsidies

Solar energy power plants need important initial investment and on the whole have low O&M costs. Consequently governments often apply financial incentives in the shape of grants as a percentage of total investment or €/kW grants.

Investment grants have been a common type of support for some years, probably because this support instrument is easy to administer.

Nevertheless plant owners are not encouraged to operate the plants as efficiently as might be the case for production-based financial supports which is the reason for some countries starting to offer financial subsidies on a production basis.

6.2.5 Tax credits

In order to develop renewable energies, many countries apply tax incentives: tax refunds for renewable electricity, exemption from investments in renewable power plants from income or corporate taxes, exemption of renewable energy from energy taxes.

Such incentives can relate to investment or production, they improve competition for these energies and are easily established and adjusted by the authorities according to circumstances.

6.2.6 Green marketing

Green marketing is not really an incentive because it depends only on consumers' volition: consumers pay voluntarily electricity at a premium to be supplied by renewable electricity only. This premium represents the additional generation cost of such electricity. In this system public awareness and willingness are obviously the crucial factors.

For the time being green marketing has not yet generally succeeded in producing a large demand for renewable electricity.

7. Which Growth for Biomass?

7.1 Long-range biomass potential

Theoretically biomass energy has enormous potential. The very long-range biomass electricity production potential is estimated at 11,000 TWh per year, i.e. more than 60% of the world-wide electricity production in 2005 (18,140 TWh). This potential is higher than that of other renewable energies: hydro (7,500 TWh), wind energy (around 4,500 TWh), Solar energy (4,400 TWh)… However, biomass must be divided amongst all uses (food, heating, electricity, bio-fuels).

In addition, if 57% of the hydro potential is already currently exploited, biomass energy is barely exploited: only 183.4 TWh produced in 2005 throughout the world, in other words 1.7% of the potential. Consequently we can expect a high growth in the biomass sector for many years, all the more as biomass energy has several interesting assets:

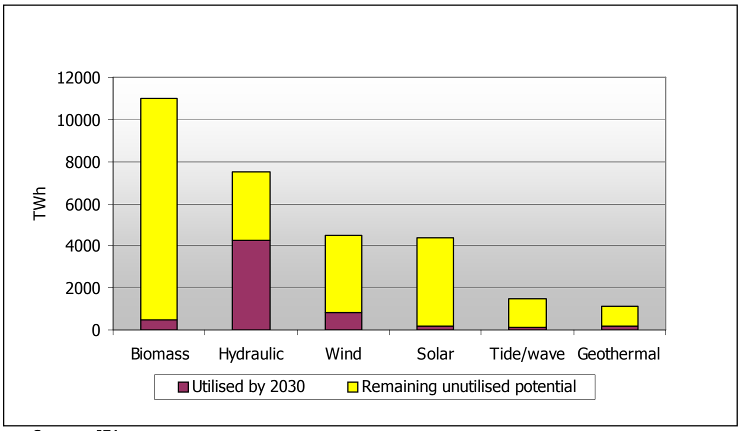
- New technologies are expected, present ones are proven
- Wastes and residues are used
- Biomass can easily substitute coal

With such assets biomass will probably be able to supply a substantial part of our electricity needs in coming decades.

7.2 Production forecasting

If we exclude hydro, biomass, wind and PV solar energies will probably be the major renewable energies in coming decades. The International Energy Agency indicates that over the next three decades, world biomass electricity production is expected to triple with an electricity production of about 600 TWh in 2030.

Biomass should represent 2% of global electricity production and 4% of OECD European electricity production in 2030. Biomass should be used mostly for the production of electricity and heat in decentralised applications in industry or district heating. A small percentage of this is likely to be used in co-firing with coal as a way to reduce CO2 emissions from coal-fired power plants.



Source : IEA

8. Conclusions

Biomass certainly has huge potential throughout the world and should be a significant source of energy in coming decades and will be able to provide heat, electricity and bio-fuels for transportation.

If Europe and North America rapidly increase their installed capacity, all countries throughout the world may use biomass power plants in sufficiently forested or agricultural areas, all the more as current technologies are proven, reliable, and costs relatively low.

Technical advancements are expected and should promote a decrease in cost and diversify solutions in order to adapt power plants to the feedstock and needs. However, biomass needs incentive mechanisms in order to accelerate in this sector, find new markets and encourage technical improvements.

Biomass is a relatively clean energy. It will certainly be beneficial and can play a sizeable role in GHG emission reduction. However, owing to the different utilisation – heat, electricity, bio-fuels and especially food – and geographically limited localisation, biomass electricity alone will be unable to supply the entire electricity needs.

A relatively clean energy mix, combining renewable energies (wind, solar, biomass, marine and geothermal energies) with nuclear, hydro and others (depending on local and regional capacities), is absolutely necessary to guarantee sufficient electricity production and reduce GHG emissions.

Appendix E

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Section 4 Conclusion and Acknowledgements

Conclusions and Recommendations for the Future

The technical, environmental and sociological performance indicators proposed by this PGP work group probably need, at least for some, to be more precisely defined, as it is presented using international norms and standards. This specific work of precise definition is a very wide work of normalisation that should be made with specialised international organisations. As they are now, the proposed indicators should provide a good basis for checking RES performances and compare these with other installations.

In order to be really efficient, these indicators should serve as a basis for the construction of databases. The best way for WEC would probably be to initiate collaborations with already existing databases like WindStats (for wind) and IEA PVPS (for photovoltaic) – see annex 4.

The state of the art documents established here for wind, photovoltaic and biomass energy could also be actualised regularly in order to synthesise the most recent information on “what’s going on” for RES in the world, in terms of electricity production, technologies, actors, costs, prospective, etc…

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Appendix G

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Appendix H

Advantages and Drawbacks of RES Technologies

	WIND	SOLAR PV	BIOMASS *	GEOTHERMAL	HYDRO
Main Advantages	Inexhaustible No emissions “Local” energy	Inexhaustible Ideal for many remote regions No polluting emissions “Local” energy Low maintenance	Cheap energy Large variety of fuel types “Local” energy Wastes elimination Agricultural reconversion	Clean, “local” and cheap energy Independent on climate or season High capacity factor Variety of direct uses	Clean and cheap energy Instantaneous energy Storage of energy
Main Drawbacks	Discontinuous Visual impacts Noise Danger to birds	Discontinuous Recycling of toxic materials Grid connection Still very expensive	Collection and transport Air pollution Season or climate dependant Competition with other uses	Limited zones	Displacement of population Impact on river ecosystems Discontinuous Risks of conflicts for share between countries

Appendix I

Complete List of Proposed RES Indicators

Performance Indicator	Type of RES	Ease of Measure	Site Comparability
Technical indicators			
Plant size (MW)	All	Easy	OK
Expected life time	All	Rather difficult	OK
Equivalent Full Load Hours (hours)	All	Easy	OK
Capacity Factor (%)	Wind, Biomass, Geothermal	Easy	OK
Load Factor (%)	Geothermal	Easy	OK
Specific Energy Production (kWh/m^2)	Wind	Easy	OK
Availability Factor (%)	Wind, Biomass, Geothermal	Easy	OK
Weather Variability Control	Wind, PV	Rather difficult	OK
Reference Yield (hours/day)	PV	Rather difficult	OK
Array Yield (hours/day)	PV	Rather difficult	OK
Final Yield (hours/day)	PV	Rather difficult	OK
Performance Ratio (%)	PV	Rather difficult	OK
Efficiency (higher heat value)	Biomass	Easy	Rather difficult
Fuel Moisture	Biomass	Easy	Rather difficult
Annual energy sent out (MWh/year)	Biomass	Easy	Rather difficult

Environmental indicators			
Duration of operation to produce the energy consumed for its manufacturing (years)	All	Rather easy	Rather difficult
Man-hours to return to original state (hours/kW)	All	Rather easy	OK
Avoided CO2 (t/MW/y)	All	Easy	Rather difficult
Q emissions CO2 during production and during the whole life cycle (g/kWh)	All	Rather easy	OK
Q emissions SO2 during production and during the whole life cycle (g/kWh)	All	Rather easy	OK
Q emissions NOx during production and during the whole life cycle (g/kWh)	All	Rather easy	OK
Land area required for 1 GW (km2)	All	Easy	OK
External cost (in €/kWh, or in% of production cost)	All	Very difficult	Difficult
Qtox toxic materials contained in the cells & batteries	PV	Difficult	OK
Qash quantities of ashes emitted (g/kWh)	Biomass	Rather difficult	OK
QCH4 quandities of CH4 emitted (g/kWh)	Biomass	Easy	OK
QH2S quantities of H2S emitted (g/kWh)	Geothermal	Easy	OK
dmin Visual / landscape protection distance (m)	Wind	Rather difficult	Rather difficult
Sf Sound at foot of turbine (dB)	Wind	Easy	OK
St Sound of turbine (dB) at standard distance H+D/2 (according to norm IEC 61400-11)	Wind	Easy	OK
S500 Sound 500m away from turbine (dB)	Wind	Rather difficult	Rather difficult
Birds killed (n/year)	Wind	Difficult	OK
Shadow casting (hours/year)	Wind	Difficult	Rather difficult
Sociological indicators			
Nj Jobs created direct (full time employees) and indirect (n/MW)	All	Rather difficult	Rather difficult
Na People access to electricity (n/MW)	All	Easy	Rather difficult
SAR number of accidents / 1,000,000 man-hours	All	Easy	OK

Note: along with these indicators, general information on the RES plants have to be provided in order to be able to compare and make useful statistics in the future. In particular, the following data will be necessary when introduced in the future data bases:

Age, Vintage, Type of technology (type of PV cells, of wind turbine wings, of biomass fuel, of geothermal technique), Cycle of operation, Estimated life time, Return time / number of years of production of electricity needed for implementation of the plants

Type of back up eventually needed when the plant is not in operation (no wind, no sun, …)

Appendix J

Flyers

Member committees of the World Energy Council

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
Ethiopia
Finland
France
Gabon
Georgia
Germany
Ghana
Greece
Guinea
Hong Kong, China
Hungary
Iceland
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
Monaco
Mongolia
Morocco
Namibia
Nepal
Netherlands
New Zealand
Niger
Nigeria
Norway
Pakistan
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
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