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Analyses of Photovoltaic Systems in Europe and the USA

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***Abstract*— This research paper analyses photovoltaic systems, which are basically renewable energy systems that can convert solar energy directly into electricity. Its exponential growth in Europe and the USA over a short period of time and the major companies involved in these regions responsible for the research and development of photovoltaic systems to meet up with the energy demands of an industrial and power demanding Green society. It further gives insight on the background, Technological Advancements, Areas of applications of Photovoltaic Systems in an attempt to shed more insight on why this technology has become so important in these regions and what the Photovoltaic System Companies there offer, their capacity, efficiency, range of its photovoltaic systems and the economics involved.**

***Keywords*— Europe, USA, Photovoltaic Systems, Technological advancement, Renewable Energy**

I. INTRODUCTION

In the world today, where developed countries and even the developing ones are undergoing researching, developing and utilizing renewable sources of energy in its bid to curb the ever increasing threat that is posed by Greenhouse gasses (GHG) emission. These GHG emission results from the excessive dependence on fossil fuel based power generation and their devastating effect on the environment and the climate, one of the most viable renewable energy alternatives available today is photovoltaic systems, which is believed will soon, in tandem with other renewable energy sources, completely replace fossil fuel based power generation systems in the near future. This complete replacement is pursued in order to achieve the dream of a greener, efficient, recyclable, sustainable energy driven society and a reduction in greenhouse gasses emission as to meet the targets set by the Kyoto Protocol [1,2].

Photovoltaic Systems (PV systems) are systems that can directly convert the end-less solar radiations from the sun into electricity. The underlying principle upon which photovoltaic systems are built is the ability of solar radiations in the form of light to liberate electrons from the atoms of a semiconductor material to generate electricity. These semiconductor materials are used in building solar cells, which are actually the tiny units that are interconnected together to form a solar panel. The solar panel is then positioned in the path of incident sun rays, which are absorbed by the solar panel to liberate a pool of electrons which flow as electricity. This generated electricity is in the form of Direct current (DC) which is further transformed to Alternating currents (AC) with the aid of an inverter and utilized for residential, commercial, industrial and other applications. The various units of a solar panel are;

- The cell: it is also called the solar cell and it is an electrical device which converts solar energy (light) directly into electricity by the photoelectric effect.
- The module: it is also called a photovoltaic module and it's basically a number of solar cells that have been interconnected in an assembly and then packaged.
- The Array: it is also called photovoltaic array which is the complete power-generating unit, consisting of a number of Photovoltaic modules.

The diagram depiction the various units of a solar panel is shown in Figure 1.

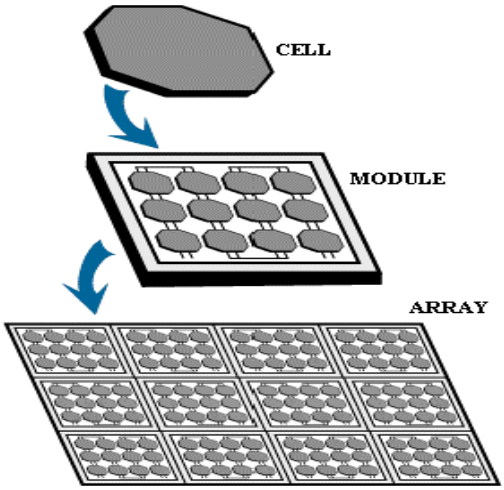


Fig. 1. *Diagrammatic representation of the various units of a solar panel*

PV systems can be designed to be able to power small loads like a few watts or less and they can also be designed for a very large scale power stations producing several Megawatts and they are broadly divided into two categories, namely; Standalone photovoltaic systems which as the name implies generate the electricity which is utilized directly or saved in a battery and Grid photovoltaic systems that involves the integration of a photovoltaic system with a power grid, this usually eliminates the need for storage

batteries. Photovoltaic system modules typically last for about 25 to 40 years [3-5].

According to the International Energy Agency (IEA), solar photovoltaic power has a particularly promising future. Global PV capacity has been increasing at an av-erage annual growth of 40% since 2000 and has significant potential for long-term growth over the next decade [4,6]. It is no surprise that the international Energy Agency has 28 member countries and among these countries, the United States of America (USA) and several European countries were its founding members. This only goes to show that this two technological giants are among the forerunners in the advancement of photovoltaic systems, its sales to other countries in the world and its strong standing among the factors leading to an increase in their economy. In this paper, the status of photovoltaic systems in Europe and the USA and the companies involved will be reviewed.

II. BACKGROUND

Sunlight is the world's largest energy source and for thousands of years, it has been human civilizations chief source of light and heat. Today, solar energy tech-nologies are being developed and refined to more effectively use the sun's power for producing electricity (photovoltaic), as well as steam and hot water for indus-trial processes (solar thermal technologies). In less than an hour, the U.S. receives more energy in the form of sunlight than it does from the fossil fuels it burns in a year [7,8].

It is interesting to note that the evolution of photovoltaic systems actually dates back to over 160 years. The principles on which todays photovoltaic system are based upon were discovered from the experiments performed by French physicist Antoine-Cesar Becquerel in 1839. He discovered that an electric current could be created by shinning line on an electrolytic cell containing two electrodes and electrolyte. This further underwent different modifications until in 1905, when Albert Einstein published a paper titled, photoelectric effect: "On a Heuristic Viewpoint Concerning the Production and Transformation of Light", to which he won a No-bel Prize in 1922. The true potential of photovoltaic cells will be felt 32 years later, in 1954 when Bell Laboratories while doing research on silicon semiconductors discovered that it had photoelectric properties and they immediately manufactured Silicon solar cells which was able to achieve 6% efficiency at the time. The manufacture of this silicon solar cell single handedly began what is now referred to as the "Commercial solar Age [9-10].

After this time countries who were at the forefront in technology at the time began formulating subsidies so as to enable a very rapid adoption of photovoltaic tech-nology as they quickly realized that the future of power generation didn't lie in fossil fuel that posed a threat to the environment directly or indirectly but in the ever abundant energy that is radiated from the sun on a daily basis. Examples of this subsidy in Europe and the USA are as follows; The German solar photovoltaic (PV) industry began with the passage of the "1000 roofs program" in 1991, in which the government gave subsidies to individuals to cover the cost of installing a PV rooftop system. The aims of the program were to gain experience with solar installations, make new housing compatible with renewable electricity generation needs, and stimulate consumer usage of solar power. By the mid1990s, 2,000 grid-connected PV systems had been installed on the Germany's rooftops [11], in the USA, President George H. W Bush directed the US department of energy to establish the National renewable energy laboratory, these two instances in history clearly shows that these Nations were seriously pursuing the usage of Photovoltaic technology to meet their energy needs and to achieve a sustainable renewable power supply.

III. TECHNOLOGICAL ADVANCEMENT IN PHOTOVOTAIC SYSTEMS/EFFICIENCY

There are a lot of technological advances in PV systems that has made it one of the most reliable sustainable energy sources in the world today. Energy efficiency and renewable energy are said to be the twin pillars of sustainable energy [12]. Some of the major technological advances in photovoltaic systems are outlined below.

- Processing of Silicon: Presently, the industrial method of producing silicon is by reacting carbon in the form of charcoal and silica at about 1700 °C. This process is called carbothermic reduction. Although this process creates metallurgical grade silicon with 98% purity, it is still not considered very efficient as a huge amount of heat energy is required and 1.5 tons of carbon dioxide gas is emitted which is also a greenhouse gas that has devastating effects to the climate. To develop more efficient production of pure silicon required for making solar cells, it has been discovered that silicon produced by the process of electrolyzing solid silica bars and reducing it to pure silicon is cleaner and more efficient. This process requires much less heat of about 800-900°C and the silicon produced is in porous form and thus, can easily be turned into powder offering more development opportunities for solar photovoltaic cells.

A. Thin Film Solar cells

In the past, the sheer size of photovoltaic cells in the form of solar panels was an issue because it limited the number of surfaces and the flexibility to which solar panels could be placed, to get as much incident solar radiations from the sun. With research and development that has happened in the field the sizes of solar cells have been reduced drastically to make solar cell thinner, smaller and more flexible in its usage. This has gone a long way in reducing the cost implications of so-lar panels over time and invariably increase its efficiency and usage. Thin-film photovoltaic cells can use less than 1% of the expensive raw material (silicon or other light absorbers) compared to wafer-based solar cells, lead-ing to a significant price drop per Watt peak capacity [13-14].

B. *Nano Wire Solar Cells*

The quest to find cheaper to be used in the creation of semi-conductor based solar cells, the Lawrence Berkeley national laboratory owned by U.S. Department of Energy developed this kind of solar cell which is cheaper to make and utilizes small spaces to generate electricity. It requires just 400 nanometers in diameters as compared to 100 micrometers in thickness that would have been needed in silicon wafers [15].

IV. Investigation of Photovoltaic Systems in Europe and the USA

Before proper analysis of a very important power generation system in two very diverse regions of the world can be made, some parameters as pertaining to the Economics and Technical parts of photovoltaic systems must be clearly defined, they are:

A. *Levelized Cost od Energy (LCoE):*

This is the price at which electricity must be generated from a specific source to break even over the lifetime of the project. It is an economic assessment of the cost of the energy-generating system including all the costs over its lifetime: initial investment, operations and maintenance, cost of fuel, cost of capital, and is very useful in calculating the costs of generation from different sources [16-17].

It can be defined in a single formula as in (1):

$$LEC = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}} \quad (1)$$

LEC = Average lifetime levelized electricity generation cost

I_t = Investment expenditures in the year, *t*

M_t = Operations and maintenance expenditures in the year, *t*

F_t = Fuel expenditures in the year, *t*

E_t = Electricity generation in the year, *t*

r = Discount rate

n = Life of the system

B. *Grid Parity*

When Photovoltaic systems are connected to the Electric Grid, it is said to have achieved Grid parity when the Photovoltaic system can generate electricity at a levelized cost (LCoE) that is less than or equal to the price of purchasing power from the Grid. It was achieved for the first time in Spain in 2013 [18].

C. *Feed in Tariff (FIT):*

This is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology [19].

D. *Energy Payback Time (EPBT)*

This is the time necessary for a Photovoltaic system to generate the energy equal to that used to produce it. It is defined in mathematical form as in (2);

$$EPBT = E_{input} \Big/ E_{output} \quad (2)$$

E. *Peak Watt*

This is defined as the power at standard test conditions (Light intensity at 1000W/m^2 , Air mass of 1.5 and temperature of 25^{o}C) it usually denoted as Wp.

F. *Cost of PV systems:*

This is a cost that is measured in price-per-peak-watt. This is usually de-noted as €/ Wp (euro-per-peak-watt) or $/ Wp (dollar-per-peak-watt).

V. Analysis of Photovoltaic Systems in Europe

For over a decade, Europe has remained at the forefront in the number of Photo-voltaic systems that has been installed and the amount of energy generated from photovoltaic systems. This very high increase in the development and investment in Photovoltaic systems was due to a reduced cost in its modules. The graph in figure 2 represents a decline in price of Solar PV systems between the years 1980 to 2000.

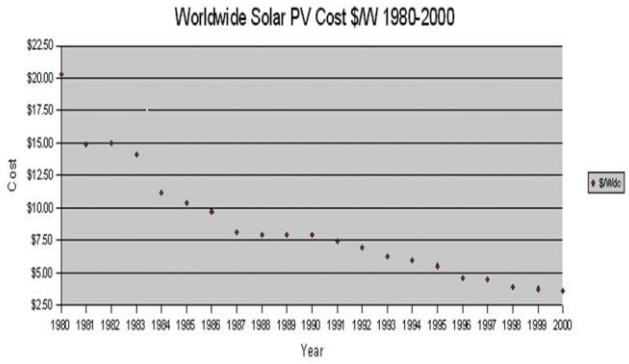


Fig. 2. *Graph depicting an almost six fold decline in the price per peak watt of PV modules from the year1980 to 2000*

The graph in figure 2 clearly depicts that as far back as the year1980, the price per peak watt for photovoltaic modules were very expensive and one reason for this was the fact that it was still a new industry when compared to other renewable energy industries like Wind power, hydroelectric power etc. which had been in use for a longer time and thus lots of advancements had taken place in these power generation systems. But at the graph goes on to show the price kept on reducing and this shows one of the factors that lead Europe to becoming the highest installers of photovoltaic systems because it invested heavily in this technology and the countries in Europe

developed policies and subsidies to aid its quick absorption of this technology as already cited in background (Page 3). According to PV Insider's Report 'markets will explode when module costs decline, but module costs can't decline much, until the market grows much larger' and this explosion in the market is exemplified by the growth of Photovoltaic systems in Europe.

PV markets in Europe and around the world continued making rapid progress in 2012 toward competitiveness in the electricity sector. The strong price decreases of PV technology, and increased Electricity prices in general, have helped drive momentum toward what is often called "grid parity". The moment is near when the savings in electricity cost and/or the revenues generated by selling PV electricity on the market could be equal to or higher than the long-term cost of installing and financing a PV system. This so-called "dynamic grid parity" appears within range in several EU countries, and has been reached already in some segments of some countries. In most countries, PV market deployment still depends on the political framework in place. Various national schemes, whether they are being introduced, modified, or phased out, have a significant influence on EPIA's fore-casts and scenarios as they have serious consequences on national PV markets and industries. As shown by the substantial regulatory changes introduced by policymakers in several countries in 2012, dedicated financial support as the main driver for PV development is progressively vanishing. In the coming years, deployment strategies will depend much more on the capacity of PV power to actively participate in the electricity system [20].

Back In 2008, the two largest installers of Photovoltaic systems in Europe was Germany and Spain, but due to Economic crises that occurred in the whole of Europe and changes in policies, Spain has since fallen from the category of the largest installers and has been replaced by Italy. In 2012, Europe increased its cumulative capacity base to 70GW, this impressive performance was driven by two markets, Germany and Italy. In terms of Global Cumulative PV systems in-stalled capacity, Europe still leads the way with 17.2GW connected to the grid in 2012 thus representing 55% of the world's annual PV capacity.

The diagram in figure 3 denotes the Photovoltaic systems, market splits for the year 2012. As seen from what has been discussed previously and the graph presented in Fig.3 above, the greatest contributor to the growth of Photovoltaic systems in Europe is Germany and thus the major and most influential Photovoltaic system companies in Germany will be briefly discussed.

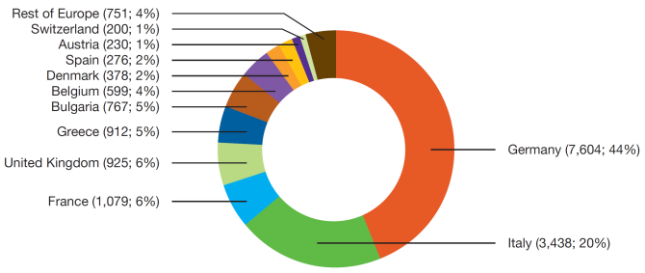


Fig. 3. *European PV market split in 2012 (MW; %) [20]*

A. Photovoltaic System Companies in Germany:

The German solar PV industry installed 7.6 GW in 2012, 7.5 GW in 2011, and solar PV provided 18 TWh of electricity in 2011, about 3% of total electricity. On midday of Saturday May 26, 2012, solar energy provided over 40% of total electricity consumption in Germany, and 20% for the 24h-day. The federal government has set a target of 66 GW of installed solar PV capacity by 2030, to be reached with an annual increase of 2.5–3.5 GW and a goal of 80% of electricity from renewable sources by 2050. From 3.5 GW to 4 GW are expected to be in-stalled in 2013. Solar power in Germany has been growing considerably due to the country's feed-in tariffs for renewable energy which were introduced by the German Renewable Energy Act. Prices of PV systems have decreased more than 50% in 5 years since 2006 [20]. As seen from this statistic, Germany has had a steady increase in the development and growth in the market in the world, but this achievement didn't come as a result of sheer luck, but rather by the efforts of various German PV companies to increase in their research, development and manufacture of PV Systems and Photovoltaic power generation plants. Some of the most important of these companies in Germany are; SolarWorld, Conergy AG, Gehrilcher Solar and IBC solar. The status of these companies, their specialization and what they offer is summarized in Tables I & II.

Although from all that has been seen concerning the market for Photovoltaic Systems in Europe and its biggest contributor Germany, it must be said that due to the very rapid rate to which other countries in the world have grown in photovoltaic technology and the impact of economic crisis in European countries among other things, it is estimated that Europe in a few will have a cumulative photovoltaic system installation lesser than China and the USA.

VI. Analysis of Photovoltaic Systems in Europe United States of America

Solar energy in the form of Photovoltaic (PV) has grown rapidly in the United States and in other countries. Both residential PV systems and utility-scale installations have experienced considerable growth. According to the National Renewable Energy Laboratory (NREL), as of April 2012, there were 42 utility-scale solar systems operating in the U.S. and another 161 systems under development (NREL, 2012). Including all types of photovoltaics, the U.S.

installed approximately 2,320 MW of grid-connected solar PV capacity in 2012, a 33% increase over the 2,047 MW installed in the first quarter of 2012. Between 2012 and 2013, the cumulative installed capacity grew from 5,161 MW to 7,962 MW. Although this growth rate is impressive, the U.S. has begun to lag behind a number of other developed countries in newly installed capacity of solar PV [20]. In the world today, the USA has the second highest PV market share outside Europe as depicted in the figure 4.

TABLE I. STATUS OF PHOTOVOLTAIC SYSTEMS IN MAJOR COMPANIES IN GERMANY

Company Name (Founded in)	**Specialization**	**Capacity**	**Economics**	**Employment**
SolarWorld (1988)	Manufacture of photovoltaic products worldwide and promotion and construction of Solar power plants and vehicles	Has the largest Solar cell manufacturing facility in North America.	.Revenue: €1.305 billion (2010) . Operating income: €192.8 million (2010) . Profit:€ 87.3 million (2010)	As at 2010, it had 2,380 employees
Conergy AG (1998)	Manufacture of photovoltaic products and construction of Solar parks	By 2007 Conergy had operations in subsidiaries in 25 countries	. Revenue: €913.5 million (2010) . Operating income: €13.8 million . Profit: 44.7 million (2010)	As at 2010, it had 1570 employees
Gehrilcher Solar (1994)	Acts a system integrator, planning, building, financing, maintaining and operating photovoltaic systems on open areas and roofs.	It is a highly preferred company in the whole of Europe for building solar parks	Revenue:€343 million(2010)	As at 2010, it had 430 employees
IBC solar (1982)	Photovoltaic specialist, offering solutions for sunlight-generated power.	In 2009, the company generated a consolidated global turnover of £857 million and by the end of 2009, IBC Solar had implemented more than 100,000 ready-to-use photovoltaic systems all over the world	Revenue: £857 million(2010)	As at 2011, it had 400 employees

TABLE II. INSTALLED SOLAR PHOTOVOLTAIC POWER CAPACITY IN GERMANY [19]

Year	Capacity (MW)	Annual Yield (GWh)	% of Consumption
1990	2	1.0	0.0
1991	2	1.0	0.0
1992	6	4.0	0.0
1993	9	3.0	0.0
1994	12	7.0	0.0
1995	18	7.0	0.0
1996	28	12	0.0
1997	42	18	0.0
1998	54	35	0.0
1999	70	30	0.0
2000	114	60	0.0
2001	176	76	0.0
2002	296	162	0.0
2003	435	313	0.1
2004	1,105	557	0.1
2005	2,056	1,282	0.2
2006	2,899	2,220	0.4
2007	4,170	3,075	0.5
2008	6,120	4,420	0.7
2009	10,566	6,583	1.1
2010	17,944	11,729	1.9
2011	25,429	19,599	3.2
2012	33,033	26,380	4.3
2013	36,337	31,000	5.2

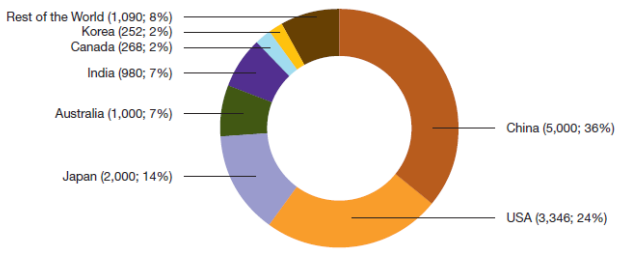


Fig. 4. *PV market share outside Europe in 2012 (MW; %) [20]*

This clearly shows that when Europe is excluded from the mix USA has a very high standing as a rapidly developing PV market with the second highest Annual Installation of PV systems presently in the world. Although when the cumulative PV systems installed in the whole world is considered, the USA drops down to 4th place as shown in Figure 5.

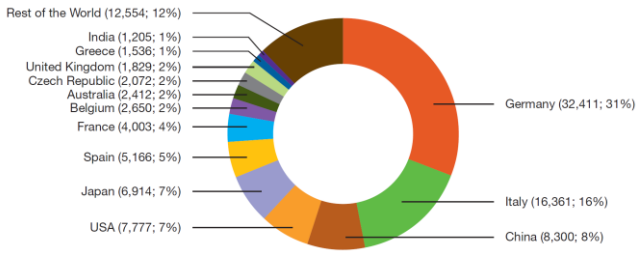


Fig.5. Global PV cumulative installed capacity share in 2012 (MW; %) [20]

Solar power in the United States includes utility-scale solar power plants as well as local distributed generation, mostly from rooftop photovoltaics. In mid-2013, the U.S. passed 10 GW of installed photovoltaic capacity with an additional 0.5 GW of concentrated solar power. In the twelve months through December 2013, utility scale solar power generated 9.25 million megawatt-hours, 0.23% of total US electricity.

The United States conducted much early research in photovoltaics and concentrated solar power. The U.S. is among the top countries in the world in electricity generated by the Sun and several of the world's largest utility-scale installations are located in the desert Southwest.

The USA like many other countries distribute Photovoltaic System plants and companies all over its fifty states. This does not however mean that all the states in the USA have the same PV ranking. California a state in the USA known for its very large landmass and the presence of deserts that favours the construction of Solar Photovoltaic parks also has the highest PV ranking in the country. Table III depicts the PV ranking of a number of states in the USA.

The USA has many solar photovoltaic parks and even the largest solar photovoltaic power plant in the world is located in the California desert. All this and more are quite impressive, but what are even more impressive are the Companies that built them. There are a number of photovoltaic systems companies in the USA, but the most important among them are; First Solar Inc., SunPower Corporation and Ever-green Solar. The table below presents a summary of these companies, their status, what they do and the economical aspects of these companies.

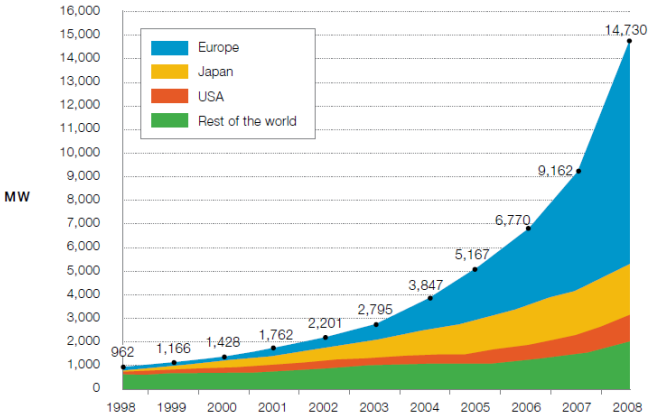
TABLE III. PV RANKINGS OF STATES IN THE USA AS AT THE FIRST QUARTER OF 2012 AND 2013

State	Rank (2012)	Rank (Q1 2013)
California	1	1
New Jersey	3	2
Hawaii	7	3
Arizona	2	4
North Carolina	6	5
Massachusetts	5	6
Tennessee	15	7
Colorado	13	8
Pennsylvania	11	9
Florida	18	10
Ohio	17	11
Missouri	24	12
New York	10	13
Vermont	21	14
Minnesota	25	15
Georgia	23	16
Maryland	8	17
Texas	12	18
Oregon	16	19
Connecticut	22	20
Washington	26	21
New Mexico	19	22
Wisconsin	28	23
Nevada	4	24
Delaware	20	25
Illinois	14	26
Washington DC	27	27

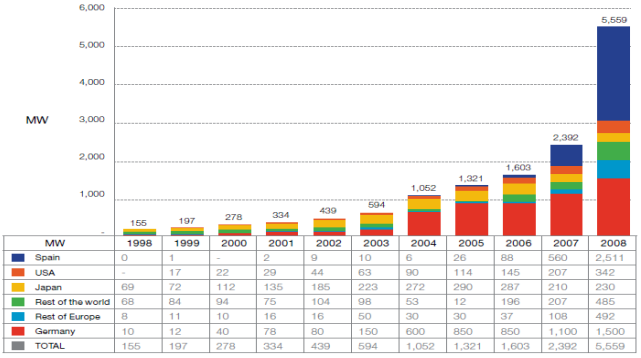
VII. CONCLUSION

After careful analysis has been made in Photovoltaic Systems from a general worldwide point of view and then specifically in the development, usage and market in Europe and the USA, it is safe to say that there is no developed country in the world today that has not invested in photovoltaic technology. Through careful observation of photovoltaic systems in Europe and the USA, it can be concluded that Europe is still far superior to the USA on a cumulative scale of the installation, utilization and market of photovoltaic systems, although in the past two years the USA has done better on the annual installation of photovoltaic systems. It can also be concluded that from all indications, renewable energy power generation systems like photovoltaic systems is the future of power production in the world and any country wishing to compete on a global scale with the developed countries and also grow its economy, has to consider photovoltaic technology as a viable means of meeting the energy demands of its country. Additional charts, information and tables that have been analysed together with the ones presented earlier can be found in appendix.

APPENDICES

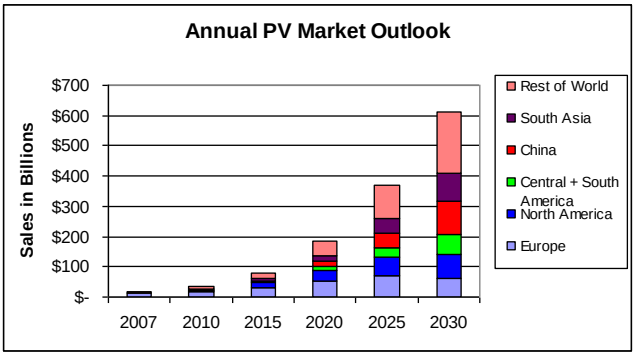


Appendix 1: Global Cumulative PV Power from 1998 to 2008



MW	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008
Spain	0	1	-	2	9	10	6	26	88	560	2,511
USA	-	17	22	29	44	63	90	114	145	207	342
Japan	69	72	112	135	185	223	272	290	287	210	230
Rest of the world	68	84	94	75	104	98	53	12	196	207	485
Rest of Europe	8	11	10	16	16	50	30	30	37	108	492
Germany	10	12	40	78	80	150	600	850	850	1,100	1,500
TOTAL	155	197	278	334	439	594	1,052	1,321	1,603	2,392	5,559

Appendix 2: Global Annual PV Market from 1998 to 2008



Appendix 3. Predictions for Annual Market Outlook from 2007 to 2030

Name of PV power plant	Country	DC Peak Power (MW)	GW·h /year	Notes
Olmedilla Photovoltaic Park	Spain	60	85	Completed September 2008
Puertollano Photovoltaic Park	Spain	50		2008
Moura photovoltaic power station	Portugal	46	93	Completed December 2008
Waldpolenz Solar Park	Germany	40	40	550,000 First Solar thin-film CdTe modules. Completed Dec 2008
Arnedo Solar Plant	Spain	34		Completed October 2008
Merida/Don Alvaro Solar Park	Spain	30		Completed September 2008
17 more 2 more	Spain Korea	Avg 20 Avg 20		
Koethen	Germany	14.75	13	200,000 First Solar thin-film CdTe modules. Completed Dec 2008
Nellis Solar Power Plant	USA	14.02	30	70,000 solar panels
Planta Solar de Salamanca 6 more Spain, 1 US, 1 Germany	Spain	13.8 Avg 12	n.a.	70,000 Kyocera panels

Appendix 4. World's largest photovoltaic (PV) power plants (12 MW or larger)

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