DECLARATION FOR THE PhD THESIS

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Thesis title:

THE POLICY DRIVERS OF PHOTOVOLTAIC INDUSTRY GROWTH IN CALIFORNIA, GERMANY, AND JAPAN

PhD in	INTERNATIONAL LAW AND ECONOMICS
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The Policy Drivers of Photovoltaic Industry Growth in California, Germany, and Japan

Thesis in partial fulfillment of the requirements for the academic degree of
Doctor of Philosophy in International Law and Economics (XXIII cycle).

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"… if we continue developing sources of renewable energy at our current average rate, we may indeed be doomed. But we won't continue at this pace because there will be a distribution of success rates, with some technologies evolving faster than others. The technologies that do evolve faster will get more funding than the others, further accelerating the advances, while the below-average technologies will be abandoned. Therefore, the expected pace of progress today underestimates the true pace of progress in the future".

Excerpt from *The Flaw of Averages: Why We Underestimate Risk in the Face of Uncertainty*,

by S. Savage (2009)

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ABBREVIATIONS

AAGR	Average Annual Growth Rate
ARRA	American Recovery and Reinvestment Act
A-Si	Amorphous Silicon
BIPV	Building Integrated Photovoltaics
BMU	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
CAGR	Compound Annual Growth Rate
CALSEIA	California Solar Energy Industries Association
CARB	California Air Resource Board
CdTe	Cadmium Telluride
CEC	California Energy Commission
CIGS	Copper Indium Gallium Diselinide
CIS	Copper Indium Diselinide
CPUC	California Public Utilities Commission
CPV	Concentrating Photovoltaics
CREBs	Clean Renewable Energy Bonds
CSI	California Solar Initiative
C-Si	Crystalline Silicon
CSP	Concentrating Solar Power
DOE EERE	Department of Energy - Energy Efficiency and Renewable Energy
EEG	Erneuerbare-Energien-Gesetz
EPBT	Energy Payback Time
EPIA	European Photovoltaic Industry Association
EPO	European Patent Office
ERDA	Energy Research and Development Administration
EREC	European Renewable Energy Council
EStG	Einkommensteuergesetz
EU-PVSEC	European Photovoltaic Solar Conference
FERC	Federal Energy Regulatory Commission

FIT	Feed-in Tariff is a policy mechanism designed to encourage the adoption of renewable energy sources. Under the FIT an obligation is imposed on electric grid utilities to buy renewable electricity from all eligible participants.
GITI	Germany Trade Invest
IOUs	Investor-Owned Utilities
IRC	Internal Revenue Code
ITC	Investment Tax Credit
JPO	Japan Patent Office
LBNL	Lawrence Berkeley National Laboratory
LCA	Life Cycle Analysis
LCOE	Levelized Cost of Electricity
METI	Ministry of Economy, Trade and Industry
MPR	The Market Price Referent is the anticipated average annual cost of generation from the power plant that would otherwise be supplying the load in that area.
MWh	Megawatt hour is a unit of energy equal to 1,000 kilowatt hours. The kilowatt hour is most commonly known as a billing unit for energy delivered to consumers by electric utilities.
MWp	Megawatt-peak is a measure of the peak output of a photovoltaic system. In photovotaics the maximum possible output of a solar generator operating under standard conditions is defined as its peak output. An optimal solar radiation of 1,000 W/m² is defined as the standard condition.
NEDO	New Energy Development Organization
NEF	New Energy Foundation
NREL	National Renewable Energy Laboratory
NSF	National Science Foundation
OPV	Organic Photovoltaics
PCE	Power Conversion Efficiency
PG&E	Pacific Gas and Electric
POUs	Publicly-Owned Utilities
PTC	Production Tax Credit
PURPA	Public Utility Regulatory Policies Act
PV	Photovoltaics
PVSEC	International Photovoltaic Solar Energy Conference

RD&D	Research, Development and Demonstration
REN 21	Renewable Energy Policy Network for the 21st Century
RPS	A Renewable Portfolio Standard is a regulation that requires the increased production of energy from renewable energy sources. The RPS mechanism generally places an obligation on electricity supply companies to produce a specified fraction of their electricity from renewable energy sources.
RWI	Rheinisch-Westfälisches Institut
SCE	Southern California Edison
SDG&E	San Diego Gas and Electric
SEIA	Solar Energy Industries Association
SNL	Sandia National Laboratories
STrEG	Stromeinspeisungsgesetz
USPTO	United States Patent and Trademark Office
WCPEC	World Conference on Photovoltaic Energy Conversion

ABSTRACT

This study is about the effectiveness of technology-push and market-pull approaches as drivers to technological change and to good performance of photovoltaic companies. While technology policy is directly aimed at stimulating the photovoltaic manufacturing industry, the policy aimed at promoting solar energy acts on the demand for electricity and only indirectly on the market performance of the photovoltaic industry. The conclusion is that a synergy of the two approaches is necessary for the growth of photovoltaic technology industry, and that government activities to promote environmentally-enhancing technological development should include both technology-push and market-pull policies during the period spanning pre-commercialization, first commercial use, and market adoption. Because of negative externalities associated with energy production and consumption, such as environmental degradation and security risks, public policy is necessary to provide an incentive for the development and diffusion of clean energy technologies. The renewable technology examined in this work is the one that converts the sunlight directly into electricity: solar photovoltaics (PV). Among clean energies, PV is the one that shows the most diverse technological paths all along the innovation curve, and it is the one that offers best opportunities for cost reduction thanks to learning curve effects. This study analyzes the PV technology industry and investigates what factors are critical for its emergence, development, and diffusion in Germany, Japan, and California. These countries were the first to invent, develop, and deploy the photovoltaic technology and are still the leaders in the PV market today. However, the results of this study can apply to any country for the design of future policies aimed at promoting clean energy technologies.

Chapter 1: Discovery, Start-up, and Development of Photovoltaic Technology

1.1 Introduction

The sun's heat and light provide an abundant source of energy that can be harnessed in many ways. There are a variety of technologies that have been developed over the past seventy years to take advantage of solar energy that can be tapped freely and extensively as a renewable and clean energy source. These include passive solar systems and active solar systems. Passive solar systems consist of *passive solar heating*, *passive cooling*, and *natural lighting.* Passive solar heating includes building orientation, window selection and placement, thermal mass to moderate temperature in floors or walls to serve as a heat sink, thus absorbing energy in the day and releasing it in the night, and back-up system to meet heating load. Passive cooling is based on minimizing sun exposure and heat absorption, allowing cool air to enter the building as well as allowing hot air to escape. Natural lighting means maximizing natural light by applying special glazing and automated control systems to windows. Active solar systems consist of *photovoltaic* devices (PV), *concentrating solar power plants* (CSP), and *solar hot water systems.* PV devices are solar cells made of semiconductor materials able to transform sun power directly into electricity. CSP plants convert sun energy collected by special mirrors into electricity through steam and turbines. Solar hot water systems are simple collectors of hot waters.

This work is about solar technology for the generation of electricity, that is active solar power systems, and in particular about the technology that converts the sunlight directly into electricity, photovoltaics. Nevertheless, this chapter describes PV generation and also gives an overview of CSP technologies. They are both aimed at the production of electricity and are complementary technologies. The choice to invest in a CSP plant or a PV installation will change according to the target market. If the market focus is on private households, business or industrial premises, then the chosen technology can only be photovoltaics, whereas if the market focus is on utility companies, then the solar energy investor will need large-scale solar installations and therefore may also opt for CSP technologies.

PV and CSP are two considerably different technologies. The main difference is that, whereas CSP converts sunlight into electricity through the production of steam and the use of turbines and generators, PV produces its output thanks to special semiconductor materials that transform sunlight into electricity directly. Another important difference is that with CSP the storage of electricity is possible through special fluids called *molten salts*, whereas in the case of PV systems the storage is more difficult, and still very expensive. The energy from the sun is abundant although intermittent, therefore PV solar power systems for generation of electricity need a back-up system in order to ensure the continuity in the energy supply during night time or in cloudy or rainy days. [1]

Moreover, CSP technology needs larger area footprints than PV. Thus if combined with the need for long days of direct sunlight, CSP would perform well only in certain geographical areas, such as Southern Mediterranean countries, Saharan Africa, and South-Eastern United States. PV systems, on the contrary, are scalable and therefore adaptable to different solutions: either off-grid or on-grid, for distributed generation on rooftops of private households and businesses, as well as for concentrated generation in utility-scale PV plants for electricity generation.[2] Nevertheless, it is true that PV is not suitable for all areas. For example in desert areas with a strong insolation, PV solar cells lose efficiency (Fig. 1.2).[3]

Additionally, from a life-cycle analysis perspective, semiconductor processing requires large amounts of energy and harmful chemicals; whereas solar thermal electric technology uses more easily processed engineering materials, such as steel, glass, and rubber. CSP may thereby provide more reliable and environmentally benign energy in a variety of economies worldwide. The only environmental issue in CSP technology is the need of large amount of water to cool the condensed steam, which can constitute a problem in regions with high insolation.

Finally, there is more opportunity for cost reduction in PV systems thanks to learning curve effects and as a result of technology innovation such as using new, less expensive, and more cost-effective materials than in CSP.

As observed, PV is a much more promising technology than CSP for two main reasons: PV offers a wider spectrum of innovation paths as well as a unique scalability, therefore allowing more opportunities for cost reduction and adoption. Nevertheless, PV has some drawbacks that need to be addressed, the most relevant of which is the lack of cost-effective energy storage systems.

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[1] According to K. Neuhoff, storage technologies will to play an important role in the long term, due to the intermittency of the solar renewable resource. K. Neuhoff, (2005), “Large Scale Deployment of Renewables for Electricity Generation”, *Oxford Review of Economic Policy*, Vol. 21 (1), Spring: 88-110.

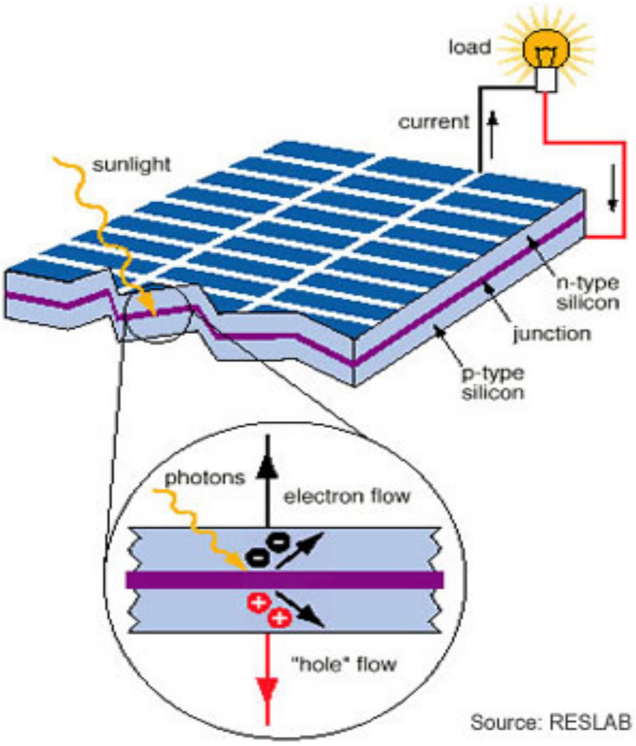
[2] There is a difference at the utilisation level of the two solar technologies, where solar power can be used in both large-scale applications and in smaller systems for the home. Businesses and industry can diversify their energy sources, improve efficiency, and save money by choosing PV solar technologies for heating and cooling, industrial processes, water heating and electricity. Homeowners can also use solar technologies for heating and cooling, and may even be able to produce enough electricity to operate "off-grid" or to sell the extra electricity to the utilities, depending on local programs. Beyond these localized uses of solar power, utilities and power plants are also taking advantage of the sun's abundant energy resource and offering the benefits to their customers. Concentrating Solar Power systems allow power plants to produce electricity from the sun on a larger scale, which in turn allows consumers to take advantage of solar power without making the investment in personal solar technology systems.

[3] S. Borenstein (2008), “The Market Value and Cost of Solar Photovoltaic Electricity Production", Center for the Study of Energy Markets Working Paper, N. 176, University of California Energy Institute: 7. Martin Green, Power to the People, UNSW Press: 20.

1.2 Solar Photovoltaics

The “photovoltaic effect” is the process of converting light (photons) to electricity (voltage), which is based on the features of some transmitting materials accurately treated (among which the silicon, an element present in nature) to generate directly electric energy when they are hit by the sun radiation. The photovoltaic cells allow direct conversion of the sun radiation into electric energy, and are made of semiconductor materials similar to those used in computer chips. Sunlight is composed of photons containing various amounts of energy corresponding to the different wavelengths of light. When photons strike a solar cell, they may be reflected or absorbed, or they may pass right through. When a photon is absorbed, the energy of the photon is transferred to an electron in an atom of the cell, which is actually a semiconductor. With its newfound energy the electron is able to escape from its normal position associated with that atom to become part of the current in an electrical circuit. By leaving this position, the electron causes a hole to form. The combined flow of negatively charged electrons in one direction, and of positively charged holes in the other direction creates a current. In conclusion, a photovoltaic cell exposed to sun radiation behaves as a generator of electric energy with a characteristic curve voltage/current, which depends mainly on the intensity of the sun radiation, but also on the temperature (Fig. 1.1 and 1.2).

Figure 1.1 The physics of PV.



1.2.1 PV History

The French physicist Becquerel discovered the photovoltaic effect in 1839, when he observed that a voltage and a current were produced when a silver chloride electrode immersed in an electrolytic solution and connected to a metal counter electrode was illuminated with white light[4]. However, the birth of the modern solar cells occurred in the United States in 1954, when Chapin, Fuller, and Pearson of Bell Telephone Laboratories demonstrated the first solar cells in *single-crystal silicon* with a power conversion efficiency of 6%[5].

From the mid 1950s to the early 1970s, PV research and development (R&D) was directed primarily towards space applications and satellite power. Only in 1973 a high level of R&D on solar cells started on the aftermath of the oil embargo that caused widespread concern regarding energy supply and caused a dramatic conventional fuels' price increase. Although solar-cell technology proved too expensive for terrestrial use until the mid-1970s, another PV application occurred in these years, when the scientist Berman, with financial help from Exxon Corporation, designed a significantly less costly solar cell by using poorer grade silicon and packaging the cells with cheaper materials. As a result, systems for the production of the first *multi-crystalline silicon* were developed.

An exception among the common directions of research and development in the field of silicon-based PV was represented by the research conducted by Ovshinsky who opened the scientific field of amorphous and disordered materials in the course of his research in the 1940s and 1950s, in the United States when he studied neurophysiology, neural disease, and cybernetics. Since then, *amorphous silicon* semiconductors[6] have become one of the main components of semiconductor industry before and photovoltaic industry later, thanks to its thinner and more flexible structure.[7] In 1973 two scientists of the Department of Electronic Engineering of the University of Virginia fabricated and demonstrated a *thin-film* waveguide photodetector based on amorphous silicon.[8]

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[4] E. Becquerel, "Mémoire sur les effets électriques produits sous l'influence des rayons solaires", *C.R. Acad. Sci.*, 9, Paris, 1839: 561-567

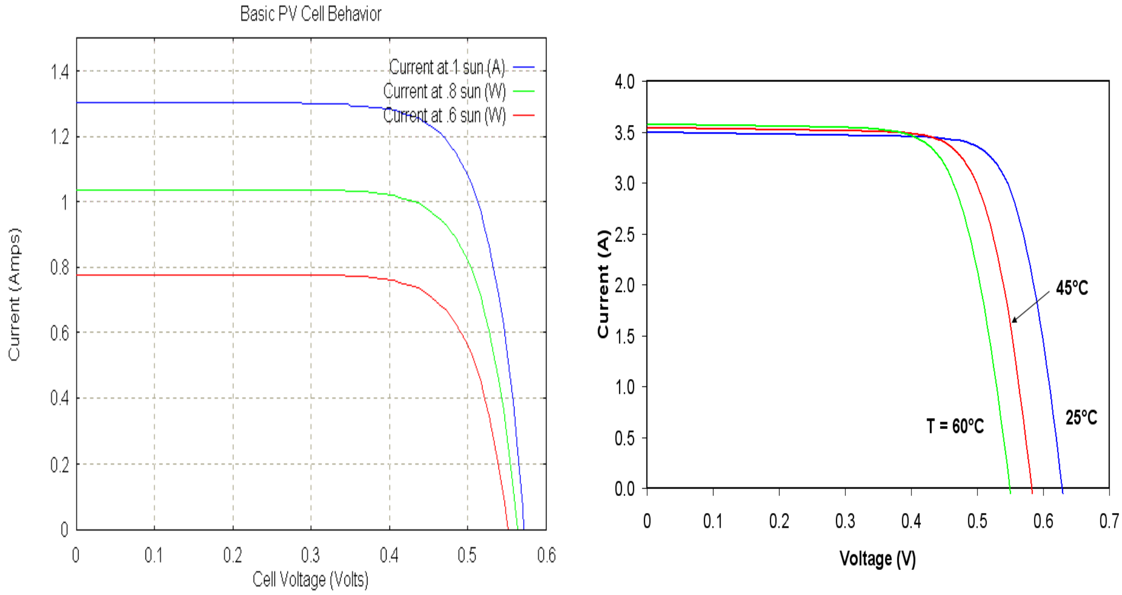
[5] D. Chapin, C. Fuller, G. Pearson, Bell Telephone Laboratories, Inc., Murray Hill, New Jersey, (1954) "A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power", *Journal of Applied Physics,* vol. 25, issue 5: 676

[6] Amorphous silicon (a-Si or α-Si) is the non-crystalline form of silicon.

[7] In 2007 the demand for polysilicon of the electronic industry was surpassed by the demand of the PV industry, representing in 2008 the 70% of the global demand for polysilicon. Energy Strategy Group, Politecnico di Milano, *Solar Energy Report, Il Sistema Industriale Italiano nel Business dell'Energia Solare*, ed. 2008: 79.

[8] M. McWright Howerton, Ted E. Batchman (1988), "A thin-film Waveguide Photodetector Using Hydrogenated Amorphous Silicon", *Journal of Lightwave Technology,* Vol. 6, issue 12: 1854-1860.

Figure 1.2 The characteristics of a PV cell. The current/voltage curve for different light intensities (left), and for different operating temperatures (right).



Only four years later, in 1977, the U.S. Department of Energy (DOE)[9], along with its PV Research and Development Program, was created and it represented the elected place for R&D in an array of new semiconductor materials for the production of silicon-free *thin-film* solar cells, such as copper indium selenide (CIS), gallium arsenide (GaAs) and cadmium telluride (CdTe). DOE, through its system of United States Department of Energy National Laboratories, as well as through many other international organizations, began funding PV R&D at appreciable levels, and a terrestrial solar cell industry quickly evolved.[10]

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[9] US DOE has been created by the Department of Energy Organization Act, signed by Carter on August 4, 1977.

[10] Office of Science, US Department of Energy, "Basic Research Needs for Solar Energy Utilization" (2005) *Report on the Basic Energy Sciences Workshop on Solar Energy Utilization*: 13

1.2.2 The Three Phases of Photovoltaic Development

Solar cells can be made from a wide range of semiconductor materials. According to the material used, the PV industry has experienced three different phases.

The first phase of photovoltaic development, from the 1950s to the 1970s, is based on silicon as the semiconductor material. *Crystalline silicon* solar cells, also known as *Wafer-Si Solar,* can be divided into two subcategories: single-crystalline silicon and multi-crystalline (also known as polycrystalline) silicon.[11]

The second phase started in the 1970s and is based on the evolution of *nanotechnologies* applied to solar cells. The Belarus scientist Zhores I. Alferov can be considered the founder of nanotechnology applications to solar cells. Thanks to his research in the field of semiconductor materials conducted at the Ioffe Physico-Technical Institute of St. Petersburg, he won the Nobel Prize in Physics in 2000.[12] *Thin-film* solar cells can be divided into four categories: amorphous silicon (a-SI), the most common; copper indium diselinide (CIS); copper indium gallium diselinide (CIGS)*;* and the most recent technology, the cadmium telluride (CdTe).

The third phase of photovoltaic development started in the 1990s and it can be identified with the development of *polymer organic* solar cells: *hybrid* solar cells and *dye-sensitized* solar cells. Instead of using an inorganic semiconductor material such as silicon, this new technology uses hybrid polymers or organic materials that can be realised in the most varied shapes and treated with gels, paints or even common food plastic layers, with the aim to exploit the same chain production characterising the press industry, the so called "roll-to-roll" system.

An example of this third generation of photovoltaics is the *dye-sensitized solar cells* (DSSC) tested for the first time in 1988 by Michael Grätzel, professor of Physical Chemistry, from the Laboratory of Photonics and Interfaces at the *Ecole Polytechnique Fédéral* de Lausanne in Switzerland. He discovered a new type of solar cell based on dye-sensitized mesoscopic oxide particles. The so-called *Grätzel cells* transform sunlight into electricity through a process very similar to the natural photosynthesis.[13] Grätzel cells are less efficient than standard silicon cells, but they have other advantages including being translucent, light-weight, and incredibly

[11] This phase is characterized by three main critiques, i.e. the high cost of silicon, combined with the oligopoly characterised the silicon market, the low efficiency and, last but not least, the need for large spaces due to the lack of flexibility of the silicon-based cells.

[12] The 2000 Nobel Prize in Physics was awarded to Zhores Alferov, Herbert Kroemer, from the University of California Santa Barbara, and Jack S. Kilby from the Texas Instruments.

[13] Artificial photosynthesis is the term given to the concept with DSC technology whereby the leaf structure is replaced by a porous titania nano-structure, and the chlorophyll is replaced by a long-life dye. The energy circuit is completed by a redox couple. This is a two-step photovoltaic process, unlike the one step process of conventional PV. B. O'Regan, M. Gratzel (1991), "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films", *Nature,* Vol. 353: 737.

efficient at converting ambient light into energy.[14] This next generation of PV has been recently investigated by other research centers in an attempt to improve efficiency level and make their use suitable for large-scale solar applications. This should pave the way to more R&D in organic materials that still present some drawbacks in the cell's durability and efficiency but also have some important advantages in terms of cost and material diffusion if compared with the more expensive silicon-based solar cells or rare inorganic compounds used in thin-film.[15]

On the other hand, for the discovery and development on the *polymers conductivity*, the American scientist Alan J. Heeger from the University of California, Santa Barbara, won the 2000 Nobel Prize in Chemistry[16], and then founded a R&D research centre on photovoltaic polymers at the Gwangju Institute of Science and Technology in South Korea. The most important advantage of this technology consists in the capacity to convert light into electricity in difficult conditions such as with artificial light and with cloudy weather. [17]

Another technology breakthrough is the one introduced in the 1980s by Martin Green, *Scientia* professor at the University of New South Wales in Sydney and one of the most well known PV scientists.[18] The Photovoltaics Special Research Centre at the University of New South Wales that Martin Green directs is one of the most prominent in the world for research on innovative *"quantum"*[19] devices for solar applications. In a recent interview Martin Green maintained that the future of PV solar energy within the next decade stands in "quantum" dots, because other semiconductor materials are too expensive and too scarce in nature.[20]

Figure 1.3 describes the PV technology curve that exhibits an S-curve in its performance improvement over its lifetime. The S-curve can be explained as the performance of a technology that, when plotted against the amount of effort and money invested, shows slow initial improvement, then accelerated improvement, and then diminishing improvement. Performance improvement in the early stages of a technology is slow because the

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[14] Dr. Gratzel won the 2010 "Millennium Technology Prize" for his development of dye-sensitized solar cells. The International Selection Committee said this about the Gratzel cells: "The excellent price/performance ratio of these novel devices gives them major potential as significant contributor to the diverse portfolio of future energy technologies".

[15] For instance, research with tobacco mosaic virus coat protein (TMVP) has been conducted in the Department of Chemistry of the University of California Berkeley (Prof Matthew Francis's lab). These research constitute a real breakthrough because it takes inspiration from the photosynthetic processes but actually derives power from photosynthetic proteins. Photons are absorbed by chlorophyll molecules in an antenna protein. The absorbed light energy is efficiently shuttled along a path of acceptor molecules to the reaction center, where it triggers release of an electron. Tracy Powell, "Photosynthesis", *Berkeley Science Review*, Spring 2009 Issue 16: 16-21

[16] He won the Nobel Prize with two other scientists: the American Alan G. MacDiarmid from the University of Pennsylvania, and the Japanese Hideki Shirakawa from the University of Tsukuba.

[17] M.A. Green (2003), *Third Generation Photovoltaics, Advanced Solar Energy Conversion*, Springer-Verlag Berlin Eidelberg

[18] M.A. Green (2000), *Power to the People,* UNSW Press: 20

[19] A "quantum" is the smallest amount of energy that can be exchanged in any physical process.

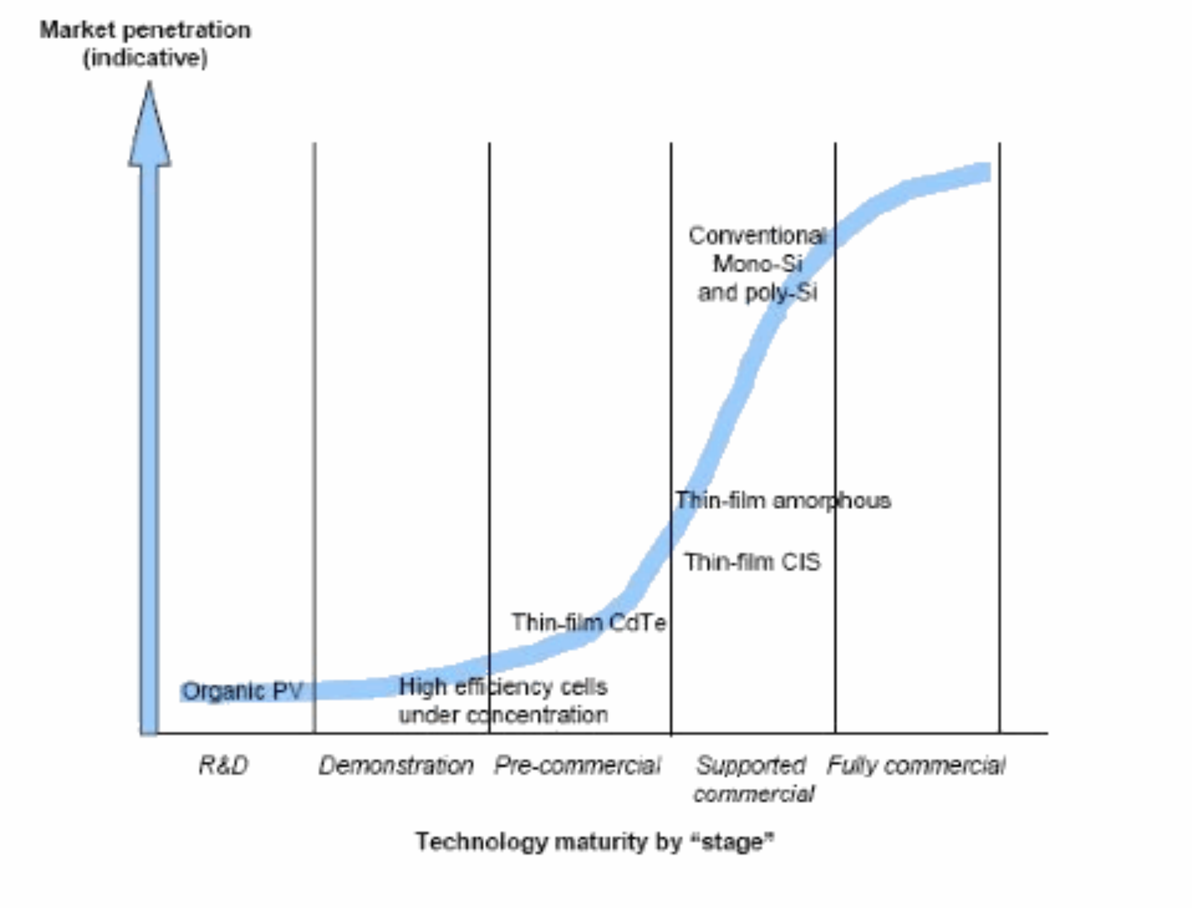
[20] G. Carovita, "Fotovoltaico nanotech", *Il Sole24 Ore,* 28/05/2009: 15

fundamentals of the technology are not yet fully understood. This is the case of organic PV, which is still in the R&D phase. However, as scientists or firms gain a deeper understanding of the technology, as it is the case with thin film solar cells and in part with high efficiency cells under concentration, improvement begins to accelerate. Finally, at some point, diminishing returns to effort begin to set in, and when the cost of each marginal improvement increases, then the S-curve flattens out. The latter would normally be the case of conventional silicon-based cells that have been developed for many years, although their performance is still improving in terms of power efficiency levels and market penetration.

In sum, c-Si dominates the market and the potential for reduced costs, from the scale-up of manufacturing plants and the introduction of new designs, indicates that c-Si could remain in this position for some more years. However, indicators of technology dynamics, such as patent activities, suggest that we have come to see a minor discontinuity where a-Si thin-film technology supersedes cells based on crystalline silicon as the dominant design approach. In the short term however, a-Si and c-Si may well have to give way to other competing designs within the thin-film family. One or both of CdTe and CIS (or CIGS) may overtake a-Si in the race towards the eventual mass market of low-cost solar cell electricity.

We will see in chapter 3 that PV firms can sometimes overcome barriers that appear to create limits to a technology's performance improvement and therefore they can actively influence the shape of the S-curve through the nature of their development activities.

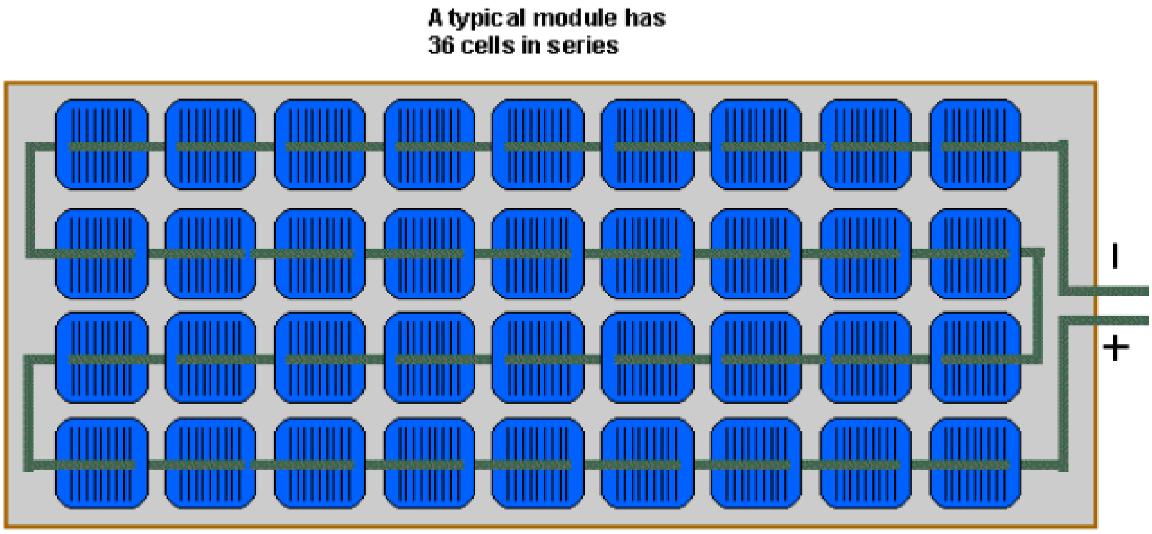
Figure 1.3 The PV technology curve.



1.2.3 PV Design and Technology

The device utilised for the production of electricity from the sunlight is the *solar cell*, also called photovoltaic cell by solar cell scientists. Solar cells, composed of *wafers* made of small slices of *polysilicon,* are typically combined into *modules* composed of at least 36 *cells* but generally composed of 48 to 72 cells, and about 10 of these modules are mounted in *PV* arrays that can measure up to several meters on a side (Fig. 1.4).

Figure 1.4 The basic structure of a PV module.



Source: C. Wadia, "Making of solar cells", class MSE 226, UCBerkeley, September 25, 2008

These *flat-plate* PV arrays can be mounted at a fixed angle facing south, or they can be mounted on a tracking device that follows the sun, allowing them to capture the most sunlight over the course of a day. About 10 to 20 PV arrays can provide enough power for a household, whereas for large electric utility or industrial applications, hundreds of arrays can be interconnected to form a single, large PV system.

Another PV system design is represented by the *Photovoltaic concentration (CPV)* that is based on the same technique developed in the CSP technology and works by concentrating solar radiation, thus allowing for the highest efficiencies from PV cells by using less silicon[21]. The most important advantage is the ability of concentrators to use less cell material in a PV system. A concentrator makes use materials such as plastic Fresnel lens to capture the solar energy and focusing it onto a smaller area, where the PV cell is. However, this system design has three important drawbacks: it requires direct solar radiation and it is therefore viable only in certain locations; it is not yet cost-effective; and the operating temperature of cells increases when excess radiation is concentrated. This creates a lot of heat and as we have observed the efficiency of the PV cell drops as temperatures increases.

Applications of this technology are: *High concentration GaAs,* Fresnel point focus applied to gallium arsenide multi-junction semiconductors, a relatively new technology that offers significantly higher efficiencies than traditional single-junction semiconductor[22]; *medium-*

[21] Photovoltaic concentration can reach higher efficiency levels than flat-plate PV systems, ranging from 12% for Fresnel line focus up to 40% for Gallium Arsenide multi-junction semiconductors.

[22] In 2009, the German Research Institute Fraunhofer ISE (Institute for Solar Energy Systems) has achieved a new world record for concentrating PV systems with an efficiency factor of 41.1%.

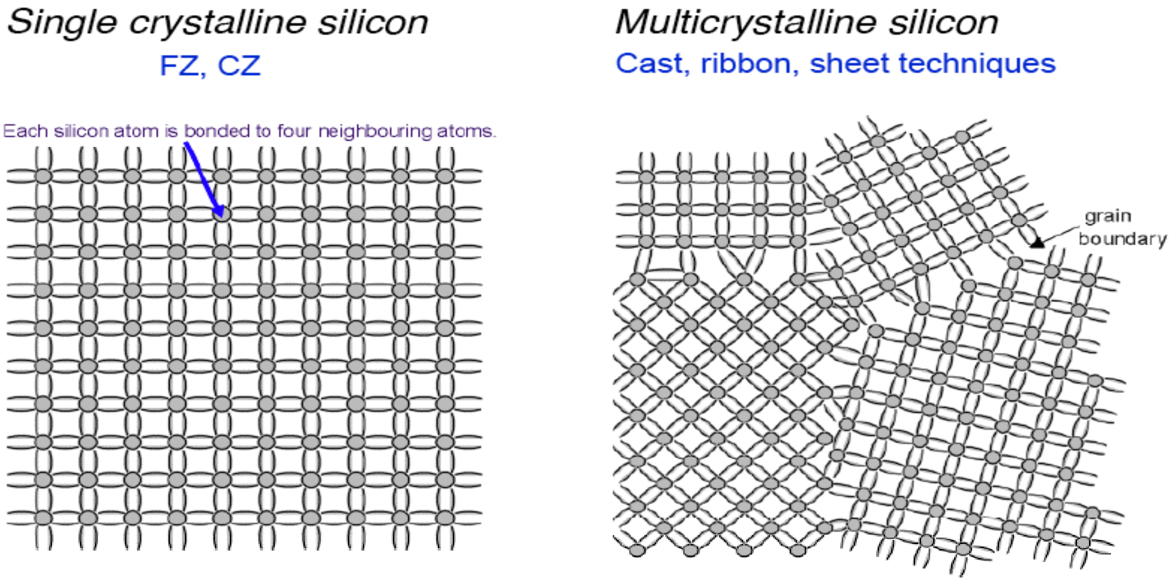
concentration Si, made of Fresnel line focus; and *low-concentration* technology, that uses mirrors instead of lenses to concentrate solar radiation.

Furthermore, PV systems have different architectural characteristics. Building-integrated PV (BIPV) are photovoltaic materials that are used to replace conventional building materials in parts of the building, such as roofs or façades. This is different from rack-mounted PV systems, which instead of integrating the system into the building simply mount the system on a pre-existing roof or façade. A last difference is between fixed PV structures and the tracking PV systems. In this last system, a moving structure is added to the PV array in order to make the PV system follow the sun and thus optimize solar irradiation. The tracking PV system offers therefore better electricity output, and it becomes necessary in certain PV technologies such as CPV that would need continuous solar radiation.

Nevertheless, as far as the technological characteristics and materials are concerned, the fundamental difference between single-crystalline and multi-crystalline silicon is primarily the density of defects and impurity, and the cost. Single-crystalline silicon provides the best quality material resulting in most efficient solar cells, but its costs are higher. Single-crystalline silicon is produced using one of two different methods: FZ-Si, *float-zone silicon*, and CZ-Si, *Czochralski grown silicon*.[23] On the other hand, casting and ribbon multi-crystalline technology have lower material costs but also lower efficiency. Sheet technology has enormous throughput per machine per day but also lower cell efficiency because of poorest material quality (Fig. 1.5).

[23] "The majority of silicon crystals grown for device production are produced by the Czochralski process, (CZ-Si) since it is the cheapest method available and it is capable of producing large size crystals. However, silicon single-crystals grown by the Czochralski method contain impurities since the crucible which contains the melt dissolves. For certain electronic devices, particularly those required for high power applications, silicon grown by the Czochralski method is not pure enough. For these applications, float-zone silicon (FZ-Si) can be used instead. It is worth mentioning though, in contrast with CZ-Si method in which the seed is dipped into the silicon melt and the growing crystal is pulled upward, the thin seed crystal in the FZ-Si method sustains the growing crystal as well as the polysilicon rod from the bottom. As a result, it is difficult to grow large size crystals using the float-zone method". Source: *Wikipedia.*

Figure 1.5 Single-crystalline silicon vs. multi-crystalline silicon cells.



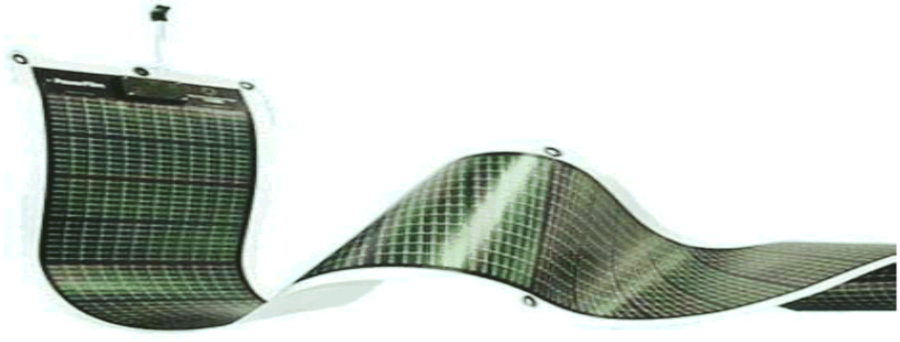
Source: C. Wadia, "Making of solar cells", class MSE 226, UC Berkeley, September 25, 2008

As observed before the thin-film technology is made of, at least, four different categories: amorphous silicon (a-SI), the most common; copper indium diselinide (CIS); copper indium gallium diselinide (CIGS)*;* and the most recent technology, the cadmium telluride[24] (CdTe) (Fig. 1.7). Thin-film is made of a mixture of materials that can be rearer in nature than silicon, but have specific characteristics which make panels made of thin film much more adaptable to different architectural solutions (Fig. 1.6).

In conclusion, the most evident difference between crystalline silicon and the second-generation technologies is not only in the material used but also in the solar cells' structure and technology design: the first is characterised by silicon-based material and by a rigid and fragile cell, whereas the latter is silicon-free and it is made of flexible and durable cells.

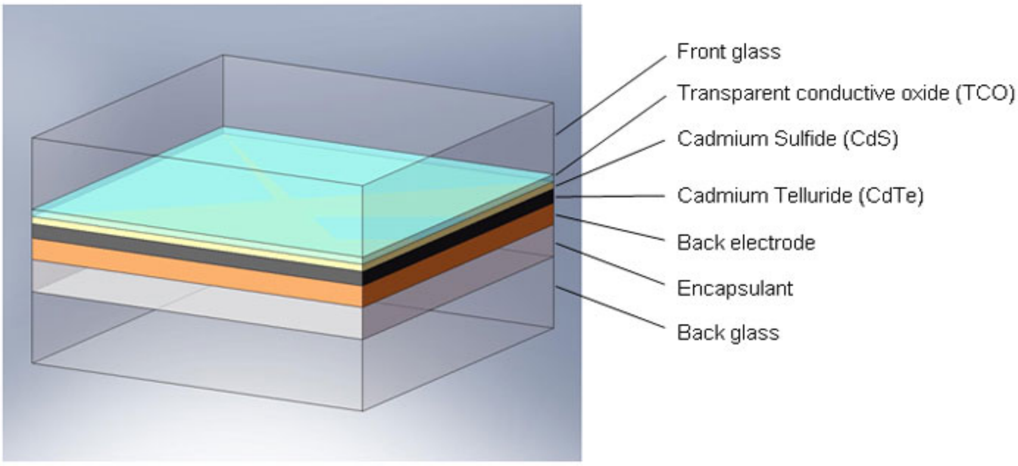
[24] This last technology is also wrongly known as entailing environmental impact because of cadmium content. Nevertheless, a study by V.M. Fthenakis, a researcher at the National Photovoltaic Environmental Health and Safety Assistance Centre of the New York States Brookhaven National Laboratory, has proved that under a Life Cycle Analysis perspective, cadmium atmospheric emissions from smelting has been drastically reduced and that although later studies assessed that PV utilization was considered the main contributor to cadmium air emission, extensive experimental tests have proved that this is not true. V.M. Fthenakis (2004), "Life cycle impact analysis of cadmium in CdTe PV production", *Renewable and Sustainable Energy Reviews,* 8: 303-334, www.elsevier.com

Figure 1.6 A Thin-film solar module.



Source: http://www.csa.com/discoveryguides/solar/images/thin.jpg

Figure 1.7 Cadmium Telluride Cell (CdTe).



Source: http://www.displayplus.net

1.2.4 Power Conversion Efficiency

The physics and economics of photovoltaic technologies are linked by performance measures. The dominant performance benchmark is the *Power Conversion Efficiency* (PCE)[25], or the ratio between the electrical power output and the light power input. It is also called *Solar Conversion Efficiency*, or the ratio between the net generating capacity and the light power input that falls on the total area of the solar cell.[26] Nevertheless, since end consumers can only buy modules and not individual cells, the most important commercial parameters for PV is module efficiency (Tab. 1.1). The entire surface of a cell is active, but when more than one cell is put together to make a module then not the entire surface is active, therefore, module efficiency is lower than cell efficiency. *Power per unit area* is another performance measure used by solar companies today to describe the power per panel or module. Other minor performance dimensions are the ability to use diffused light, proven reliability, and flexible design.

Figure 1.8 illustrates the best laboratory cell efficiency levels reached from 1975 to 2010. The efficiency levels have improved dramaticaly from 1976, when laboratory efficiency ranged from less than 1% for thin-film amorphous silicon to 9% for thin-film cadium telluride technology, to today, when gallium arsenide multi-junction solar cells have exceeded 40% laboratory efficiency. Nevertheless, it is worth noting that there hasn't been any major push for new basic science R&D for solar PV in 20 years, meaning that there has been a lack of investment in new materials (emerging PV) from the late 1970s to the late 1990s.[27] Nevertheless, in recent years many improvements have been made in the field of solar cells R&D conducted on new materials, both organic and inorganic semiconductors as active photogenerating materials. As an example, the impressive amount of research projects at the UC Berkeley, where there are several multi-disciplinary research groups. Among others, the group led by Professor Alivisatos at the Department of Chemistry and the Department Material Science Engineering, in coordination with the Lawrence Berkeley National Laboratory, is at the cutting edge of the scientific exploration of new inorganic material systems (pyrite-based solar cells or FeS2)[28]. Another group is the one led by Professor Francis at the Department of Chemistry is conducting cutting-edge research on organic material for photovoltaic use (tobacco mosaic virus coat protein or TMVP).[29]

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[25] PCE takes into account the effects of shading, snow cover, heat loss, and DC-AC conversion loss.

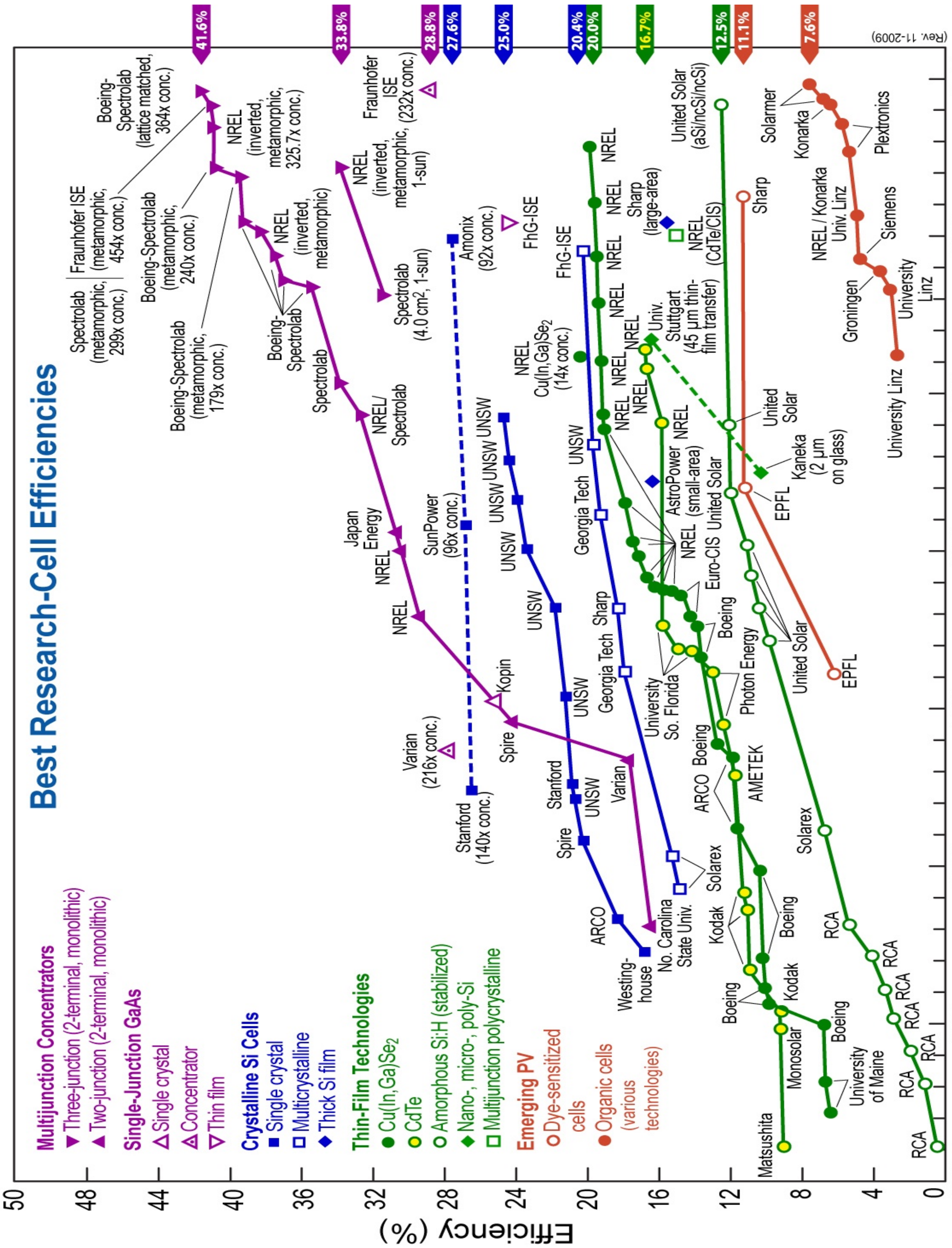
[26] PCE, where an optimum is determined by open circuit voltage (Voc) and short circuit current (Jsc), as given in the relationship η) (VocJscFF)/Pin, where FF is the material fill factor and Pin is the incident solar energy.

[27] C.Wadia, *"How to Bring Solar Energy to Seven Billion People*", Conference LBNL, Berkeley, April 16, 2009

[28] C. Wadia, A.P. Alivisatos, D.M. Kammen (2009), "Materials Availability Expands the Opportunity for Large-Scale Photovoltaics Deployment", *Environ. Sci. Technol*., 43 (6): 2072-2077

[29] "T. Powell (2009), "Photosynthesis", *Berkeley Science Review*, Issue 16: 16-21

Figure 1.8 Historical PV research cell efficiency and developing laboratories (1975-2010).



Source: NREL, 2010

Table 1.1 Solar modules' maximum Power Conversion Efficiency (PCE).

Cell Type	***Technology Phase***	***Module Efficiency (PCE)***	***Company***
Mono-Si	Supported commercial	19.3%	SunPower
Poli-Si	Supported commercial	14.5%	Q-Cells
CIGS	Supported commercial	11.2%	Q-Cells (Solibro)
Thin-film CdTe	Supported commercial	10.4%	First Solar
Thin-film a-Si	Supported commercial	8.0%	Chint Solar

Source: "Solar Modules Survey", *Photon International* 2-2010

1.2.5 Energy Payback Time

Life-cycle analysis in the photovoltaic industry is a very important factor to take into consideration. Any anthropogenic means of energy production, including solar, generate pollutants when their entire life cycle is accounted for. A life cycle starts from the mining and processing of materials that make solar cells, modules, and balance of system, and ends at their final decommissioning, disposal and/or recycling. The *Energy Payback Time* (EPBT) is the length of deployment required for a PV system to generate an amount of energy equal to the total energy that went onto its production. Life-cycle analysis results vary according to the different PV technology characteristics. The EPBT varies according to three main factors: the power conversion efficiency of the PV system; the amount of insolation that the system receives; and the manufacturing technology used to make the PV solar cells. The third characteristic is the one described in table 1.2. Here it can be observed that the Cadmium Telluride has 1 year EPBT, and the energy required for producing its system does not exceed 3.7% of the total energy generated by the system during its anticipated operational lifetime. This means that the deposition of thin layers of non-crystalline-silicon materials on inexpensive substrates requires the least energy intensive technology. The single-crystalline silicon technology has a EPBT of 2.7 years, and the energy used for manufacturing the solar cell does not exceed the 10% of the total energy generated by the system. Therefore, this EPBT is not too high considering that single-crystalline silicon cell is the most energy intensive technology.

Table 1.2 System energy payback times for different PV module technologies.

Cell Technology	***Cell durability (yr) (1)***	***Energy Payback Time (EPBT) (yr) (2)***	***Energy used to produce system compared to total generated energy (%) (3)***	***Total energy generated by system divided by amount of energy used to produce system (4)***
Single-crystalline silicon	n/a	2.7	10.0	10
Non-ribbon multicrystalline silicon	20	2.2	8.1	12
Ribbon multicrystalline silicon	20	1.7	6.3	16
Cadmium Telluride	n/a	1.0	3.7	27

Source (1): C. Wadia *et al*. (2009)

Source (2): V. Fthenakis, E. Alsema (2006)

Source (3) and (4): DOE (EERE), Solar Energy Technologies Program: Photovoltaic Basics, www1.eere.energy.gov/solar/printable_versions/pv_basics.html (We assume 30-year period of performance and 80% maximum rated power at end of lifetime).

1.2.6 The PV Value Chain

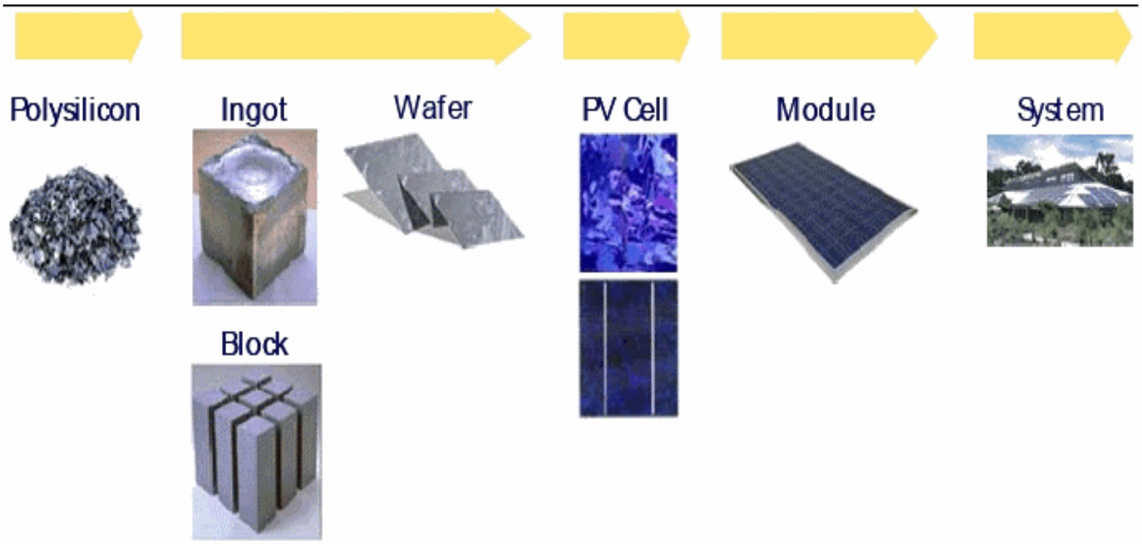
For every PV components, silicon and other semiconductor materials, cell, wafer, module, as well as for other materials (inverter, tracker, battery storage, auxiliary power sources, charge controller, mounting structures, conductors, AC and DC power handling equipment) a different market exists. For the purpose of this work, we only focus on the basic components of a PV array, whereas production of inverters and other non-PV module components are not taken into consideration.

The PV crystalline-based technology value chain can be divided into three main production stages (Fig. 1.9), of which the first two are vertically integrated:

1. silicon and wafer (silicon feedstock is produced and processed into ingots that are cut into squares. Wafers are sliced from the squared ingots);
2. cells and modules (cells are produced from the wafers, and then put together in modules);
3. system production (systems are produced from the modules and installed).

In the chapters that follow, we focus on the already-assembled PV technology i.e., cells and modules.

Figure 1.9 The PV value chain.

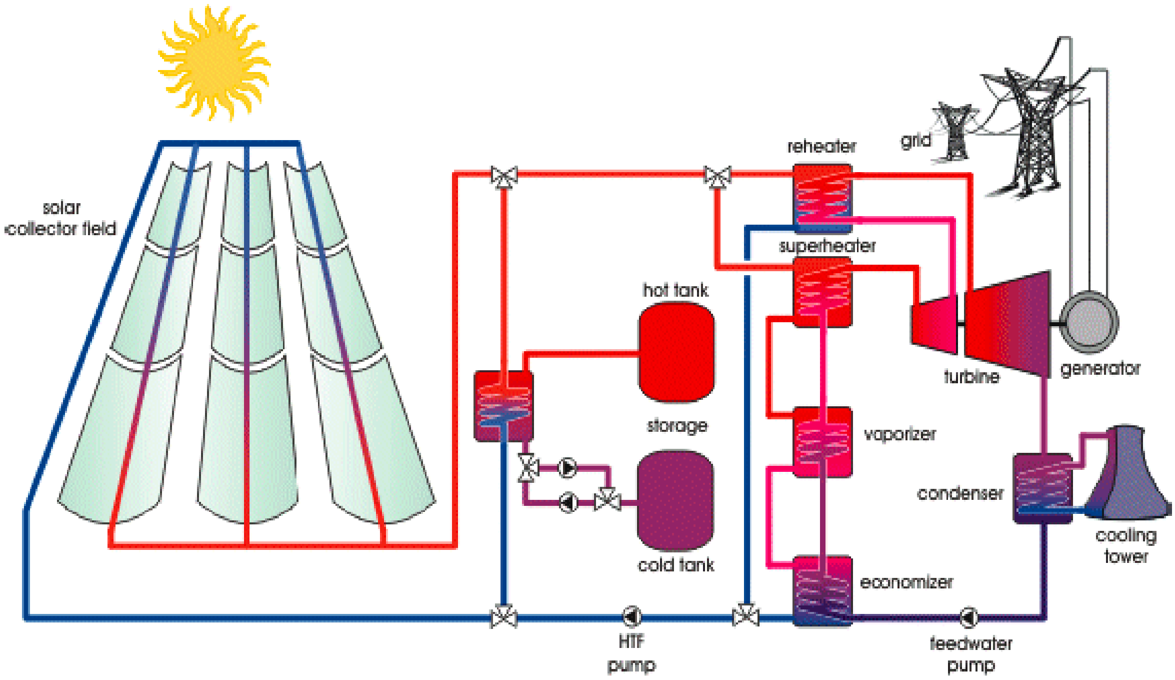


Source: European Photovoltaic Technology Platform, SEIA

1.3 Concentrating Solar Power

The Concentrating Solar Power, or solar thermal electric, is a system to produce electricity through a process similar to the one utilized in conventional power plants that use conventional energy sources, such as fossil fuels, as a heat source to boil water. The steam derived from the boiling water spins a large turbine, which drives a generator to produce electricity. CSP technology needs direct sunlight and therefore tracking systems to capture the sunlight in the different times of the day are necessary. The sunlight is collected, through parabolic dishes or mirrors into a focal point where the energy is stored thanks to a liquid with a high conductivity potential (Fig. 1.10).

Figure 1.10 The functioning of a CSP plant.



Source: Tester, J. W., E. M. Drake, *et al.* (2005)

1.3.1 CSP History

The history of Concentrating Solar Power technology dates back to the Roman times in 213 B.C. during the siege of Syracuse. At that time Archimedes invented a system that succeeded in destroying the Roman fleet thanks to the use of energy from the sun produced through a mirror made up of metal shields reflecting sun rays into the enemy vessels and burning them.[30] Thanks to Archimedes suggestions, the modern solar thermal energy exploits the sun radiation through different kinds of mirrors to produce energy and rays are oriented in a way to increase the internal energy and thus to high up the temperature of a transfer fluid. Giovanni Francia (1911 – 1980), the Italian scientist considered as the father of thermodynamic solar plants, in 1964 created the first CSP Fresnel system demonstration plant in Marseille, in collaboration with the French scientist Marcel Perrot (1908 – 2006).

The development of modern concentrating solar technologies started in the first half of 1970s in the same years of the 1973 oil crisis, when an initiative of the International Energy Agency gave birth to a large-scale research program for the production of electricity via thermodynamics. Other demonstration areas were spreading in the 1980s all over Europe[31] and in the Mojave desert in California where parabolic trough systems plants, called SEGS (Solar Energy Generating Systems), were installed by the US/Israeli Luz International group[32].

At the beginning of 1990s the Concentrating Solar Power represented a growing technology and industry. Nevertheless, after twenty years of boom for CSP, the end of the oil crisis accompanied by a lack of long-term incentive policies to renewable energies determined a stop to the development of this technology. As an example, the United States Department of Energy cut the funds to Concentrating Solar Power R&D because it considered the quota of national research allocated to this technology and developed at the National Renewable Energy Laboratory at Sandia as not sufficient to be competitive with other renewable energy technologies.

After fifteen years of lethargy, new CSP plants have been built. In Europe, the PS10 solar tower plant built by Abengoa Solar near Sevilla was Europe's first commercial concentrating solar power. In the United States, projects in operation are increasing considerably in these last years, to add to the California's Ausra Linear Fresnel and the eSolar Sierra SunTower projects.

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[30] A.A. Mills, R. Clift (1992), "Reflections on the "Burning Mirrors of Archimedes"", Eur. J. Phys. 13: 266.

[31] Plataforma solar de Almeria, Spain; the demonstration area of DLR (Deutsche Zentrum fur Luft-und Raumfahrt), in Koln, Germany; the base of CNRS of Odeillo, France; the Paul Sherrer Institute of Villigen, Switzerland; the Eurelios of Adrano, Sicily (1980 - 85) that was built in 1980 and was used as a ENEL technological observation plant.

[32] The Israeli enterprise Solel took over the management of Luz International after its bankruptcy in 1991. Now there exist nine SEGS plants in California and they are owned and run by NextEra Energy Resources.

Many other plants are under development and others under construction both in Europe (Spain and Italy) and in the United States, mainly in California, but also in the rest of the world, with a greater development in the North of Africa and the Middle East.[33]

1.3.2 CSP Applications

There are three different families of CSP systems that are: linear concentrator technology, parabolic dish technology, and power tower systems.

1.3.2.1 Linear Concentrator Technology

This technology consists of collecting the sun's energy using long rectangular, curved (U-shaped) mirrors. The mirrors are tilted toward the sun, focusing sunlight on tubes (or receivers) that run the length of the mirrors. The reflected sunlight heats a fluid flowing through the tubes. The hot fluid then is used to boil water in a conventional steam-turbine generator to produce electricity. There are two major types of linear concentrator systems: parabolic trough systems (Fig. 1.11), where receiver tubes are positioned along the focal line of each parabolic mirror; and linear Fresnel reflector systems (Fig. 1.12), where one receiver tube is positioned above several mirrors to allow the mirrors greater mobility in tracking the sun. This system allows energy storage thanks to the hot fluid composed either of synthetic oil or melted salt. According to the president of the German Fraunhofer Institute, professor Hans-Jorg Bullinger, "Energy storage in power grids is one of the twelve frontline themes that we will be intensively working on over the coming years in order to meet challenges such as climate change".[34] The maximum electricity production capacity of linear concentrators is up to 80 MW.[35] This technology is the most mature, it is in fact in the commercialisation phase, and the parabolic trough system is also the most diffused among the other CSP technologies.[36]

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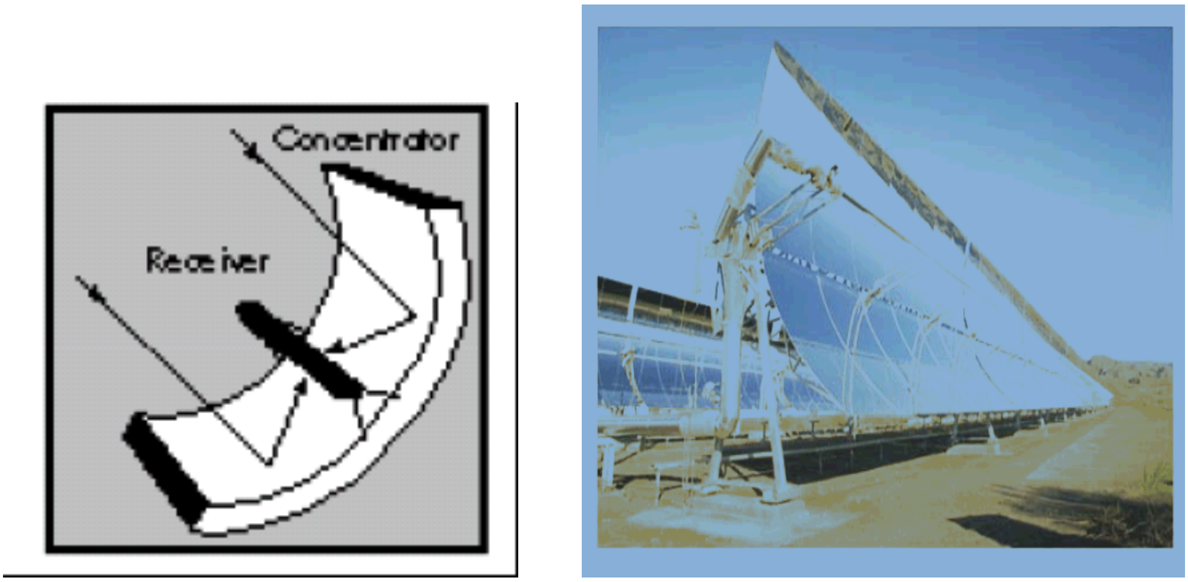
[33] In California: SES Solar One and Two, San Joaquin Solar 1 and 2, Harper Lake Energy Park, Carrizo Energy Solar Farm; in Europe: Archimede (Italy); Solnova 1 Andasol 1, Extresol, Puertollano Solar Plant, Almaden (Spain); In the Middle East and North Africa: Shams (UAE), Asharim (Israel), Kuraymat Plant (Egypt), Hassi R'mel (Algeria), Ain-Ben-Mathar (Morocco), YSTPP (Iran).

[34] M. Horn (2009), "Reliable electricity from sun and wind", in *Fraunhofer Magazine,* n. 1: 20-21.

[35] Energy Strategy Group, Politecnico di Milano, (2008), *Solar Energy Report, Il Sistema Industriale Italiano nel Business dell'Energia Solare*: 135-145.

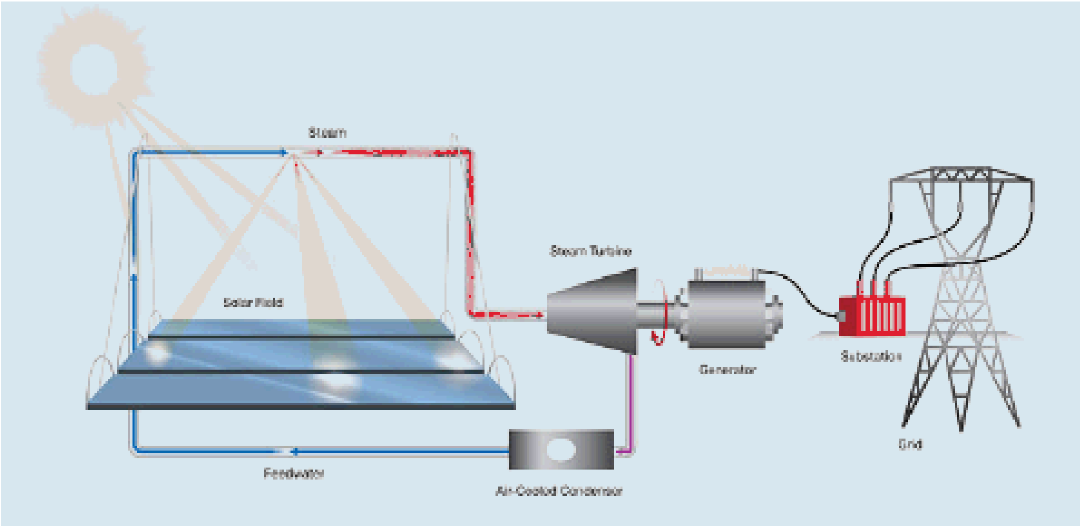
[36] *Solar Energy Report , op. cit.:* 137-142 and 149.

Figure 1.11 CSP Linear concentrator technology: Parabolic Trough System.



Source: http://www.eere.energy.gov/de/csp.html

Figure 1.12 CSP linear concentrator technology: Linear Fresnel Reflector System.



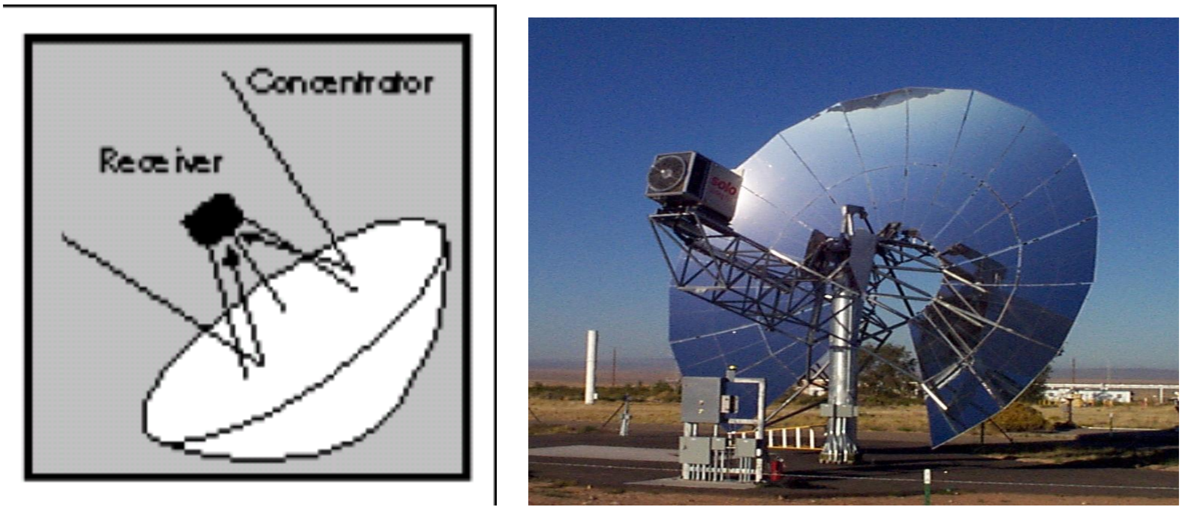
Source: http://www.gizmag.com/first-us-thermal-solar-manufacturing-plant/8522/picture/40601/

http://www.largescalesolar.org/technology.php

1.3.2.2 Parabolic Dish Technology

Parabolic dish technology uses a mirrored dish similar to a very large satellite dish. The dish-shaped surface directs and concentrates sunlight onto a thermal receiver, which absorbs and collects the heat and transfers it to the engine generator (Fig. 1.13). The most common type of heat engine used today in dish systems is the Stirling engine that is in a pre-marketing phase. This system uses the fluid heated by the receiver to move pistons and create mechanical power. The mechanical power is then used to run a generator or alternator to produce electricity. Parabolic dish technology has some important drawbacks due to the lack of energy storage capability and a limit in the electricity production capacity up to 25 KW. This technology is still in the demonstration phase.[37]

Figure 1.13 CSP parabolic dish technology system.



Source: http://www.eere.energy.gov/de/csp.html

1.3.2.3 Power Tower Systems

Power tower systems consist of a central receiver tower and a large field of flat, sun-tracking mirrors known as heliostats to focus and concentrate sunlight onto a receiver on the top of a tower (Fig. 1.14). A heat-transfer fluid heated in the receiver is used to generate steam, which, in turn, is used in a conventional turbine generator to produce electricity. Some power towers use water/steam as the heat-transfer fluid. Other advanced designs are experimenting with molten nitrate salt because of its superior heat-transfer and energy-storage capabilities. The energy-storage capability, or thermal storage, allows the system to continue to dispatch electricity during cloudy weather or at night. The electricity production capacity of power tower system reaches 10 MW.[38]

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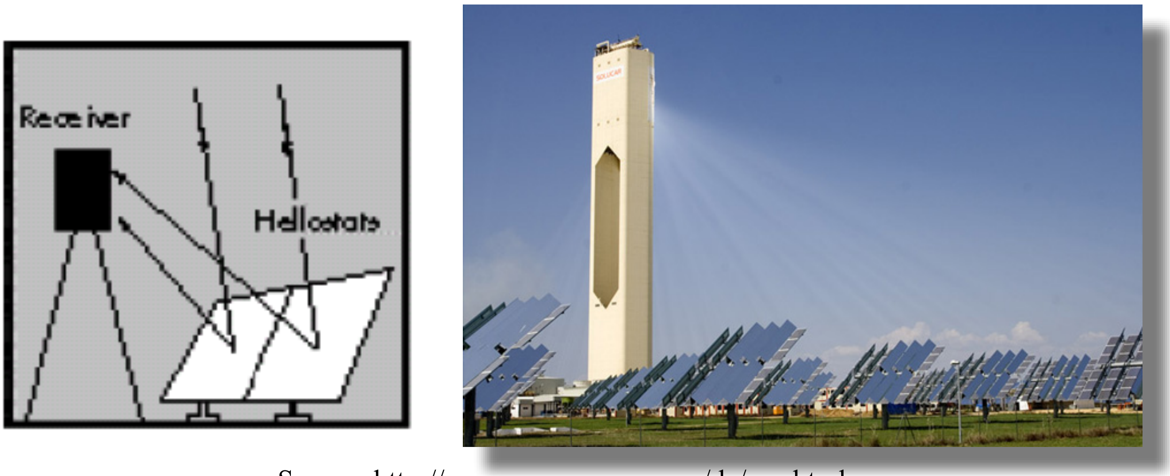
[37] *Solar Energy Report, op. cit.*: 142

[38] One of the newest technology is the one developed by US BrightSource Energy, the proprietary of Luz Power Tower (LPT) 550 energy system, that is based on proven power tower technology and is designed to offer the highest operating efficiencies, due to two-axis tracking system and to higher temperature steam production, the lowest capital costs in the industry, due to commodity-based inputs, no concrete foundations, and fewer pipes and cabling, and the lowest environmental impact, due to less water usage.

Figure 1.14 CSP power tower system.



Source: http://www.eere.energy.gov/de/csp.html

Table 1.3 Characteristics of the three main CSP architectures.

	Parabolic Trough	***Parabolic Dish***	***Power Tower***
Applications	Grid-connected plants	Stand-alone applications	Grid-connected plants
Advantages	Commercially available; storage capability,	Very high conversion efficiencies; modularity.	Good mid-term prospectives for high conversion efficiencies; storage at high temperatures.
Disadvantages	Lower temperatures	Lack of storage capability	Capital cost projections yet to be proven

1.3.3 The CSP Value Chain

Concentrating Solar Power value chain is made up of different stages: materials; components; finished products, including solar technology and plant development, also known as Engineering Procurement & Construction (EPC); distribution also known as Operations & Maintenance (O&M); and utilization by utilities companies or end users (Fig. 1.15).

Research and Development is an integral part of the component, product, and distribution stages of the value chain. Much of the R&D, plant development, manufacturing, plant design and installation, and operation are conducted by a single company or by closely related companies. Therefore, there is significant vertical integration across the five stages of the value chain.

The components stage is one of the most delicate in the CSP production process due to the high technological demand of solar thermal systems. The production of components is coordinated by the activity of project management and technological integration. The Engineering Procurement & Construction (EPC) is the activity aimed at the realization of the CSP plant, including logistics. The Operations & Maintenance (O&M) is the activity that ensures the correct and continuous functioning of the plant, entailing all the administrative obligations linked to the ownership of the plant as well as the energy trading activity.

Figure 1.15 CSP value chain.

Source: G. Gereffi and K. Dubay (2008)

1.4 Conclusion

This chapter did not mean to be exhaustive in the explanation of solar energy technologies, nor to be comprehensive from a technical standpoint, but it was meant to provide the reader with useful tools to understand the technology and its energy policy implications (Chapter 2), as well as PV industry and market structure (Chapter 3). As mentioned before, this work will focus only on the technology that transforms solar energy directly into electricity: photovoltaics.

The choice of the countries under analysis: Germany, Japan and the United States, with a focus on California, is explained by the fact that they represent the cradle of photovoltaic technology where the first phases of the technology adoption lifecycle: invention, early adoption, and early majority, found their origins with the birth of an infant industry. They also represent the countries where PV industry has grown the most, thanks to a combination of technology-push and market-pull policies, until they reached high global competitiveness and the first positions among PV producing countries.

Chapter 2: Policies and Measures to Promote Photovoltaic Technology in the US and California, Germany, and Japan

2.1 Introduction

Following the widespread recognition of the role that technology plays in economic growth (Solow 1956), this chapter intends to illustrate the policies that have contributed to the development of photovoltaic technology and thus to the growth of the PV industry in the United States (Sec. 2.2) with a focus on California (Sec. 2.3), in Europe (Sec. 2.4) with a focus on Germany (Sec. 2.5), and in Japan (Sec. 2.6).

We have divided the chapter into sections, one for each analyzed country, and subsections depending if the analyzed policy was adopted through a technology-push or a or market-pull approach. According to the technology-push approach, "advances in scientific understanding determine the rate and direction of innovation", whereas in the demand-pull approach, market forces are the drivers of the rate and direction of innovation. [39]

In this study, we follow the work by Dosi (1982) who found a strong correlation between R&D and innovative output, and the work by Nemet and Kammen (2007) who found the R&D time series were well correlated with patents across a veriety of energy technology including PV. These works imply a "linear model" of innovation. A linear model is a progression from basic science to applied research to product development to diffusion of commercial products. The linear model entails that non-incremental innovation (also radical or discontinuous innovation) occurs at the beginning of technology innovation chain and that it is implemented through technology-push policies. On the other hand, the linear model entails that incremental innovation (innovation on the same product to satisfy unmet needs or solve problems) is made at a later stage of the innovation chain and it is implemented through market-pull policies (Freeman and Perez, 1988).

Very few people defend such an understanding of innovation anymore: "Everyone knows that the linear model of innovation is dead", claimed Rosenberg (Rosenberg 1994).[40] Mowery and Rosenberg believe that demand and technology-push must exist simultaneously (Mowery and Rosenberg, 1979), and incremental and non-incremental innovations are not two unrelated entities, but they are both developed along the entire innovation chain.

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[39] G.F. Nemet (2009): 701

[40] N. Rosenberg (1994): 139.

Following these works, our thesis makes the assumption that technology innovation is not a linear process, but we assume that R&D is always needed all along the innovation path, and it needs both to anticipate and to follow the deployment of the technology into the market. Therefore, our approach considers technology-push and market-pull policies as complementary and potentially able to stimulate each other's investment. They are not substitute, but they both constitute an essential factor for the development of technology innovation, especially in the photovoltaic field.

This chapter addresses first and for each analyzed country the technology-push policies that affect technological development in the PV industry. They can be divided as follows: direct government RD&D funding to private firms or government laboratories, or RD&D contracts and grants with universities; and indirect support for PV development, such as RD&D tax credits, patent protection, public procurement, and demonstration projects. Second, the chapter addresses the market-pull policies or promotion measures that spur the production of electricity from photovoltaic energy sources, such as: renewable portfolio standards, feed-in tariffs, investment tax credits, net metering programs, rebates and loan programs for the installation of PV panels.

2.2 Solar Energy and Technology Policies in the United States

Solar energy policy in the United States can be traced back to the end of the 1970s when a *Federal Tax Credit* establishing a 15% tax credit for solar energy was introduced with the aim of stimulating the solar industry. On the other hand, US solar technology policy can be traced back to the mid-1970s in the aftermath of the first Oil Crisis. The US administration focused on energy independence and invested public funds in renewable energy sources, including solar energy for electricity generation: photovoltaics.

Among energy policies that have been adopted in the United States to support photovoltaic deployment, renewable obligations known in North America as renewable portfolio standards (RPS) play in our opinion a major role at the state level. RPS require utilities to source a certain percentage of their electricity from renewable sources generally through systems of tradeable certificates. We see that the RPS in California, regardless of the lack of a specific obligation in terms of electricity from solar energy, is one of the highest in the United States as for the overall renewable energy requirement.

Other significant energy policies and economic incentives for solar energy capacity expansion include federal and state tax incentives, federal loan guarantees, state renewable energy funds[41], voluntary green power markets[42], and the economic competitiveness of renewable energy relative to other generation options.

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[41] The first Clean Energy Fund was born in the State of California in 1998.

As for technology policies to implement innovation in solar technologies these are: direct government funding to universities, research centers, and the private sector RD&D (that spur private investment in RD&D projects), and undirect support through RD&D tax credits and patent protection.

This section is structured as follows: Section 2.2.1 analyses the US solar technology policy, through the major acts passed by the Congress since the 1970s implementing direct government funding to solar energy RD&D. Then, it investigates indirect support such as RD&D tax credits (Sec. 2.2.1.1), and patent law and policy (Sec. 2.2.1.2). Section 2.2.2 explores the US federal energy policy and financial incentives to solar energy through the analysis of major legislations and regulations adopted since the 1970s. Section 2.3 examines solar energy policies and incentive regulations from a state-level perspective. For the purpose of this study, the State of California is chosen as an example of best practice for the development of the US PV industry, both for the unique role that the Golden State has played in technology innovation, as well as for the innovative regulations and incentive measures adopted.

2.2.1 US Solar Technology Policy

The Federal government effort in solar energy Research and Development was a four-stage process. First, from 1971 to 1974, both the US Congress and the administration viewed solar as simply futuristic energy options closely tied to the US space program. Second, between 1974 and 1980, solar technologies were catapulted into serious consideration in response to the 1973 and 1979 oil embargoes. During this time period all branches of government were most active, and most of the legislation and administrative initiatives came into being. Third, the years 1981-1988 represented an inactive or even regressive period when the President and the US public had little interest in energy matters and when the Reagan administration was ideologically opposed to solar energy and instituted policies to close down federal programs in these technologies. Reagan ideologists tied solar energy to the environmental, “antigrowth” movement. The fourth period, from 1989 onward, is the rebirth period.

In the years preceding the 1973 oil embargo, solar matters were buried within the National Science Foundation (NSF), whose role was focused on basic research and not on technology development. In the short aftermath of the "energy crises" both the Congress and the US administration reacted with a sense of urgency. More than 25 solar and renewable energy bills were introduced in the 93rd Congress[43], and the budget for solar programs in NSF rose from

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[42] The Chicago Climate Exchange (CCX), a private organization that has put together the nation’s first greenhouse gas emissions credit trading system. (The cities of Berkeley and Oakland in California are members of the CCX). M.B. Gerrard ed. (2007), *Global Climate Change and US Law*, American Bar Association: 433-434 and 614-615.

[43] 93rd Congress met in Washington, DC from January 3, 1973 to January 3, 1975, during the end of Nixon's presidency, and the beginning of Ford's.

$4 million in 1973 to $ 12 million in 1974. This was the time period when the environmental community was beginning to rally behind solar energy, and was the time when the "Congressional Solar Coalition" was formed in the Congress.[44] By 1974 and 1975, the Congress was geared up to take a more activist role. Congress was ready to deal with national legislation in response to increased media and public interest for renewable energy development. In June 1975, the Energy Research and Development Administration (ERDA)[45] submitted to President Ford (1974 – 1977) and the Congress a report entitled: "A National Plan for Energy Research, Development and Demonstration: Creating Energy Choices for the Future" (ERDA-48). Within the context of the President's energy independence goals, this initial National Plan recommended energy R&D goals, discussed federal and private sector roles in energy R&D, and examined the potential timing and contribution of solar energy technology for supplying as much as 25% of the nation's future energy needs by 2020. [46]

By April 1977, President Carter (1977 - 1980) announced his *National Energy Plan*[47] that placed greater emphasis on solar energy and makes ERDA to form the US Department of Energy (DOE). But it was through this effort that key supporters of solar energy would develop, and that the energy plan was ensured of balance. By October 1977, when the DOE came into existence, the Congress was already concerned that the President was not pursuing the renewable energy options fast enough".[48]

The two major bills that became law in the post 1973 energy crisis were the *Solar Energy Research Development & Demonstration Act of 1974*[49] and the *Solar Photovoltaic Energy Research and Development Act of 1978*[50]. The first act was signed into law in 1974 and

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[44] Spark Matsunaga (D-HI), Charles Percy (R-IL), Birch Bayh (D-IN), Jacob Javits (R-NY), Paul Tsongas (D-MA), and Gary Hart (D-CO) had become legislative leaders in renewable energy in the Senate, while George Brown (D-CA), Norm Mineta (D-CA), Jim Jeffords (0-VT), Tom Blanchard (D-MI), Stephen Neal (D-NC), and Dick Ottinger (D-NY) had emerged as the solar leadership group in the House of Representatives. In fact, it was the staffs of this group of legislators who made full-time efforts to organize and coordinate the Congressional Solar Coalition.

[45] The agency was created as part of the Energy Reorganization Act of 1974 that was passed in the wake of the 1973 oil crisis.

[46] S. Sklar (1990), "The role of the Federal Government in the Commercialization of Renewable Energy Technologies", in *Annual Review Energy*, Vol. 15:121-132. Downloaded from arjournals.annualreviews.org by University of California - Berkeley on 11/20/09.

[47] For a detailed analysis of the National Energy Plan J. A. Bereny (1977), *Survey of the emerging solar energy industry*: 6

[48] S. Sklar (1990), *op. cit.,*:121-132.

[49] Pub. L. No. 93-473, 42 U.S.C.A. § 5551-66. It establishes a Solar Energy Research Institute to perform research functions in connection with the Project activities under this act and calls for the creation of a Solar Energy Information Data Bank. J.A. Bereny (1977), *Survey of the emerging solar energy industry,* Solar Energy Information Services, San Mateo, CA, May: 18-19.

[50] Pub. L. No. 95-590, 42 U.S.C.A. § 5581. It provides for an accelerated program of research, development, and demonstration of solar photovoltaic energy technologies leading to early competitive commercial applicability of such technologies to be carried out by the Department of Energy, and other Federal agencies. http://thomas.loc.gov

authorizes a vigorous federal program of RD&D with the goal of providing the option of utilizing solar energy as a viable source for the Nation's future energy needs. In response to the mandates of this act the ERDA prepared the "Preliminary Definition Report" entitled the "National Solar Energy Research Development and Demonstration Program" (ERDA-49)[51]. Unlike the *Solar Energy Research Development & Demonstration Act*, which entails the promotion of federal RD&D in all solar technologies for electricity generation, the *Solar Photovoltaic Energy Research and Development Act* is referred specifically to photovoltaics. In this act, not only was a long-term research and demonstration effort established in the field of photovoltaics, but also federal technology procurement was included. In particular, another act called the *Federal Photovoltaic Utilization Act of 1978*[52] established the procurement program, which was the first real solar commercialization effort in the United States. This act enhanced technological innovation thanks to the establishment by the Secretary of Energy of a photovoltaic systems evaluation and purchase program designed to insure that such systems reflect the most advanced technology. Finally, the *Federal Photovoltaic Utilization Act* authorized the appropriation of $98 million for FYs 1979 - 1981 to carry out such program.

In this context of stimulus to solar technology research and development, FY1978 DOE budget appropriations for solar energy reflected the RD&D requirements mainly for individual small-scale solar technologies. It is worth noting that PV and CSP received very different portion of the 1978 RD&D budget. CSP received around one-fourth of the total 1978 solar R&D budget. Photovoltaics on the other hand received $57 million, half of which would be used for research and development of lower cost or more efficient photovoltaic cells, and the remainder was scheduled for demonstration projects, government purchases and test facilities.[53]

In 1980, the 96th Congress enacted the *Energy Security Act*[54] creating the Solar Energy & Energy Conservation Bank. This was a premier program lobbying effort of the environmental community to provide an $800 million for homeowners to receive subsidized loans or outright grants for active and passive solar applications. Nevertheless, in 1981, when President Reagan came to office, the solar R&D program changed drastically and decline in funding followed, reflecting his ideological opposition to solar energy. The first signal of the imminent regressive period in solar RD&D was the announcement by the President that the solar panels on the White House would be removed followed, in February 1982, by the request advanced by the President to rescind all FY1982 Bank funds.[55]

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[51] Bereny, *op. cit.:* 17. Within this program it is ERDA's responsibility to inform the public about progress of solar technologies through research, development and demonstration stages. Therefore, an integral and substantial part of the National Solar Energy Program affects technology transfer and information dissemination in order to stimulate a public solar energy market and promote the development of solar industries.

[52] Pub. L. No. 95-619, Title V, part 4

[53] The Mitre Corporation, "Solar Energy: A comparative analysis to the year 2020", MITRE Technical Report MTR-7579, Virginia, August 1978: 16.

[54] Pub. L. No. 96-294 (1980).

[55] See Rescission Proposal No. R-82-22 H. Doc. 97-140.

From $155 million in FY1981, funding for photovoltaic research fell to $35.5 million in FY1989, when the Bush administration (1988 - 1992) requested a further cut to $25 million for FY1990.[56] Although this period was characterized by solar RD&D funding underdevelopment, some positive notes were registered. Originating within the House of Representatives in 1988, the *H.R. Bill No. 1216* called for increasing levels of funding for all solar energy technologies over three years plus joint venture projects. Also, in FY1991, the Bush administration took a volte-face by increasing photovoltaics through the *Photovoltaic Manufacturing Initiative* (+$4 million). The Solar Energy Industries Association (SEIA) called these increases "a bold attempt by the Administration to reinvigorate the Federal solar research program and demonstrate to our international competitors that the United States hasn't given up on solar energy development."[57] Although the first years of Bush presidency were not very promising in terms of R&D investments in solar technologies[58], it appeared that President Bush's National Energy Strategy was more "pro-solar" than its predecessor, if we consider the increase of solar energy budgets in FY1992 ($114 million) and FY1993 ($113.8 million).[59]

With Clinton election (1992 – 2000) it appeared as if the solar advocates had good reasons to be optimistic about the future of federal support for solar R&D. This optimism was based on Clinton's emphasis during his presidential campaign on the triad of natural gas, energy efficiency and renewables. In order to expand the use of solar President Clinton favored shifting the mission of national laboratories from defence R&D to commercial applications of solar energy. The major energy strategy documents issued by the DOE during the Clinton administration were the *National Energy Policy Plan* (1995), followed two years later by the *Strategic Plan* (1997), and the *Comprehensive National Energy Strategy* (1998).[60] Each of these documents focused on similar goals: energy production and efficiency, national security and environmental sensitivity. Although Clinton administration was keen on adopting many laws in favour of the development of a solid renewable and solar energy industry, it should face a strong opposition in the Congress, which dwarfed many of these attempted legislations.

During the first George W. Bush Presidency (2001 – 2004) the energy focus shifted substantially towards national security. The *Energy Policy Act of 2003*[61] aimed at enhancing energy conservation and research and development, and to provide for security and diversity in the energy supply. Solar energy was given only minor attention at Title XIX of the act, the

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[56] The Bush administration also proposed further cuts of 15% for solar thermal power research, from $15 million in FY1989 to $13 million in FY1990, when the budget for this category was cut yearly from $121 million since FY1981.

[57] Skar, *op. cit.*: 125.

[58]At the time of his election, the federal solar energy R&D budget was at its lowest point since FY 1975. Yet, by the end of four years the solar budget had increased by 94% from FY 1989.

[59] Just as the 93rd Congress (1973-1975) was inspired to action by an energy crisis, so was the 102nd (1991-1993). In fact, with the invasion of Kuwait by Iraq, an embargo occurred of both Kuwaiti and Iraqi oil.

[60] J.P. Tomain, R.D. Cudahy (2004), *Energy Law*, Thompson West, MN: 70

[61] H.R. 6, 108th Congress (2003)

one referring to "Extension and Modification of Renewable Electricity Production Tax Credit", which amended the Internal Revenue Code to extend and modify the renewable electricity production tax credit to include solar energy.

With the second Bush's Presidency (2004 – 2008), the energy focus shifted towards a more responsible renewable energy policy, and when the new *Energy Policy Act of 2005*[62] was enacted, it contained many provisions on solar energy. Among others: the act directed the Secretary of Energy to conduct programs of renewable energy research, development, demonstration, and commercial application, including photovoltaics[63]; also the act instructed the Secretary to establish a program for the demonstration of innovative technologies for solar energy in governmental buildings.[64]

Furthermore, in 2006 the Solar America Initiative (SAI) was launched as a US Department of Energy effort to make solar electricity from photovoltaics and concentrating solar power cost-competitive with conventional forms of electricity from the utility grid.[65] Thus, the goals were to reduce solar energy production costs through R&D and to eliminate market barriers through deployment. To achieve these goals the SAI allocated funding to universities and national laboratories, as well as to industry through public-private partnerships, state governments and federal agencies. Through the R&D activities of the SAI, the DOE intended to fund industry teams to reduce cost and scale up production across the all PV value chain. On the market standpoint, DOE conducted activities in the area of market transformation to lower market barriers and capitalize on large-scale solar deployment opportunities.

In December 2007 *the Energy Independence and Security Act*[66] was enacted and contained many provisions on solar energy R&D. Subtitle A of Title VI of this act may be cited as the "Solar Energy Research and Advancement Act of 2007". At § 603 it requires a study and report on methods to integrate utility-scale photovoltaic systems into regional electricity transmission systems, identify new transmission or transmission upgrades needed to bring electricity from high concentrating solar power resource areas to growing electric power load centers, and finally at § 604 it establishes a grant program for states that demonstrate advanced photovoltaic technology.

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[62] Pub. L. No. 109-58 (2005)

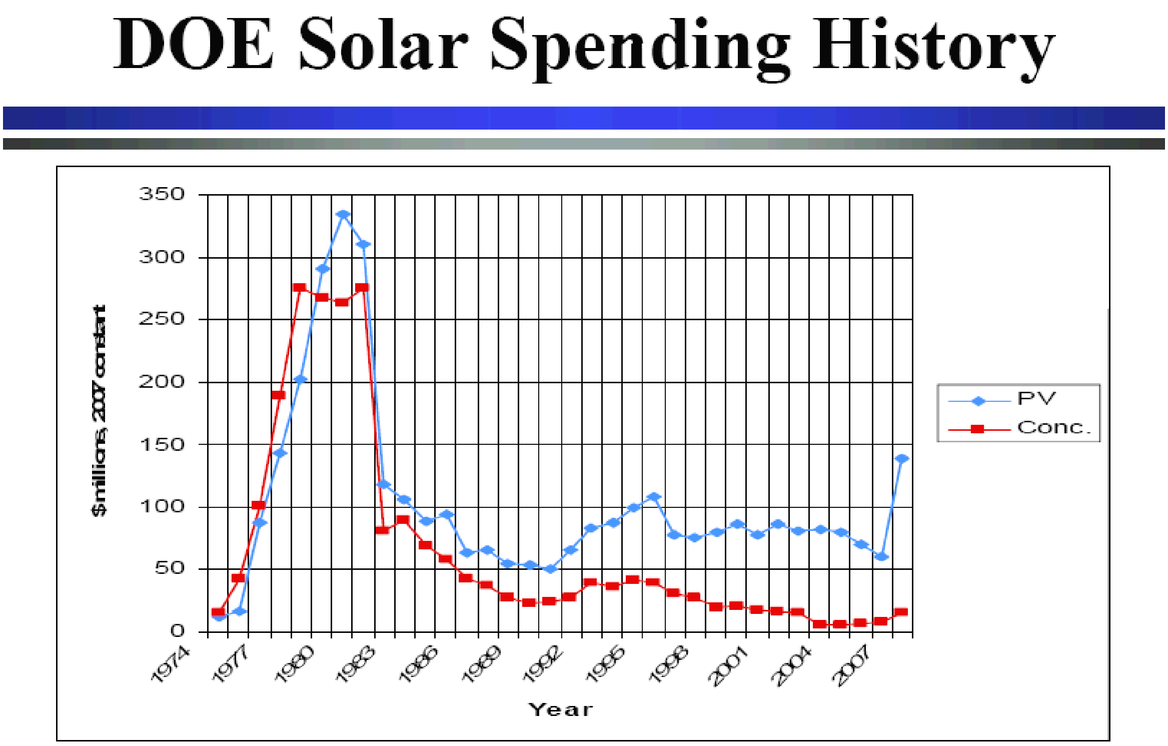
[63] Pub. L. No. 109-58, § 931 (2005)

[64] Pub. L. No. 109-58, § 935 (2005)

[65] When Federal solar energy began in the 1970s, the cost of electricity from solar resources was about $2.00 per kWh. Thanks to technological advances the cost of electricity has decreased in the last two decades by more than 90% to about 20c per kWh.

[66] Pub. L. No. 110-140 (2007)

Figure 2.1 Solar spending history in the US (1974 – 2007).



Source: DOE budget history tables; DOE Congressional budget requests; and Federal Budget FY2009, Hist. Tables, Table 10.1.

2.2.1.1 Research and Development Tax Credit System

R&D tax credits for private firms that invest in technology innovation can be classified as an indirect governmental support for the development of PV technologies. The US Internal Revenue Code (IRC) provides not only general (non-incentive) R&D tax credits provisions (IRC §263), but also three different forms of special tax incentives for research and development expenditure. They can be listed as follows: 1. Qualified expenditure incurred for R&D in the experimental or laboratory sense (including the cost of obtaining a patent) that can be *deducted* if they are in the nature of revenue expenditure, but they can be subject to *amortization* if they are in the nature of capital expenditure (IRC § 174); 2. A 20% tax credit can be claimed by taxpayers who increase R&D expenditure over a base period amount of gross receipts, without distinction between basic research costs and commercial development costs (IRC § 41 (a)(1))[67]; 3. A 20% tax credit can be claimed by taxpayers who increase basic

[67] IRC § 41 (a)(1) with provisions on the 20% tax credit was originally enacted in 1981. It has additional requirements to insure that the research is technological in nature and related to improving the business of the

research meaning original investigations for the advancement of scientific knowledge that does not have a commercial objective (IRC § 41 (a)(2)). It is worth noting that this latter R&D credit applies to payments made from corporations to qualified institutions to conduct R&D, thus including universities.

Three peculiarities of US R&D tax credit system exist. First, the tax treatment does not differentiate whether the R&D expenditure was incurred within the country or in a foreign jurisdiction. Therefore, the territorialization issue does not apply as regards the tax treatment under the general scheme of taxation, whereas for tax incentives under IRC §41 the research performed outside the US, Puerto Rico or any possessions of the United States (extramural R&D expenditure) is excluded. Second, as observed the same tax treatment is guaranteed in case of subcontracted research and no permission is required. Third, the US does not provide specific tax incentives to R&D expenditure under wage tax legislation, meaning that there are no tax benefits granted to employers with respect to withholding taxes on salaries paid to employees who perform R&D.[68]

The *Emergency Economic Stabilization Act of 2008* extended the 20% R&D tax credits. The R&D tax credit would have expired December 2007, but the provision would be extended retroactively to January 2008 and through the end of 2009. Under this act R&D expenditure incurred by the solar energy industry would qualify for the credit.[69]

In conclusion, tax credits are popular tools in the United States, although controversial because they are difficult to target toward particular technologies. In our opinion, this constitutes a limit if they need to target R&D in different photovoltaic energy technologies.

2.2.1.2 Patent Law and Policy

Another technology policy tool that is a powerful incentive for innovation in the PV industry is the protection of intellectual properties. "To the extent that potential economic returns motivate individuals and organizations to develop new technologies, policies to protect inventions, know-how, and other intellectual property can be important components of an overall innovation strategy"[70]. Nevertheless, the weakness of patent protection is that the stronger the protection, the weaker the incentives for diffusion because of fear of spill-over effects. This especially is valid in the PV industry where imitation and circumvention is easier than in other industries, such as chemicals or pharmaceuticals.

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taxpayer. Technological nature means that the process of experimentation used to discover the information must rely on principles of the physical or biological sciences, engineering, or computer science.

[68] International Bureau of Fiscal Documentation (IBFD), "Tax Treatment of Research and Development Expenses", December 2004

[69] Pub. L. No. 110-343 (2008)

[70] J. Alic, D.C. Mowery, E.S. Rubin (2003), "US technology and innovation policies. Lessons for climate change", Pew Center on Global Climate Change, November: 27

The turning point in the US policy of patent protection was the *Bayh-Dole Patent and Trademark Amendments Act of 1980* (hereinafter Bayh-Dole Act).[71] This act permitted universities and government laboratories to file for patents on the results of federally funded research and to grant licenses to patents awarded. Although the Bayh-Dole Act sought to speed commercialization of federally funded R&D, its overall effects are uncertain. Despite a rush by US universities to patent research results in the wake of the act, only a limited number of highly profitable patents were issued.[72] Moreover, efforts by universities to negotiate complex or restrictive licensing agreements as a condition for collaboration with industry may have in fact created strains to the important university-industry research collaboration.

Nevertheless, in the PV industry the correlation between patents granted and public R&D funding actually preceded the Bayh-Dole Act. This is shown in figure 2.2 that describes this strong correlation from 1970 through 2005. Kammen and Nemet (2007) use records of successful US patent applications as proxy for the intensity of inventive activity and find strong correlations between public R&D and patenting across a variety of energy technologies, among which solar PV.[73]

Looking at figure 2.2 we can observe that since the early 1980s both public sector R&D and patenting have been highly correlated and have exhibited consistently negative trends, with just an exception in the first half of the 1990s when there was a positive trend in the public R&D spending in photovoltaic technology.

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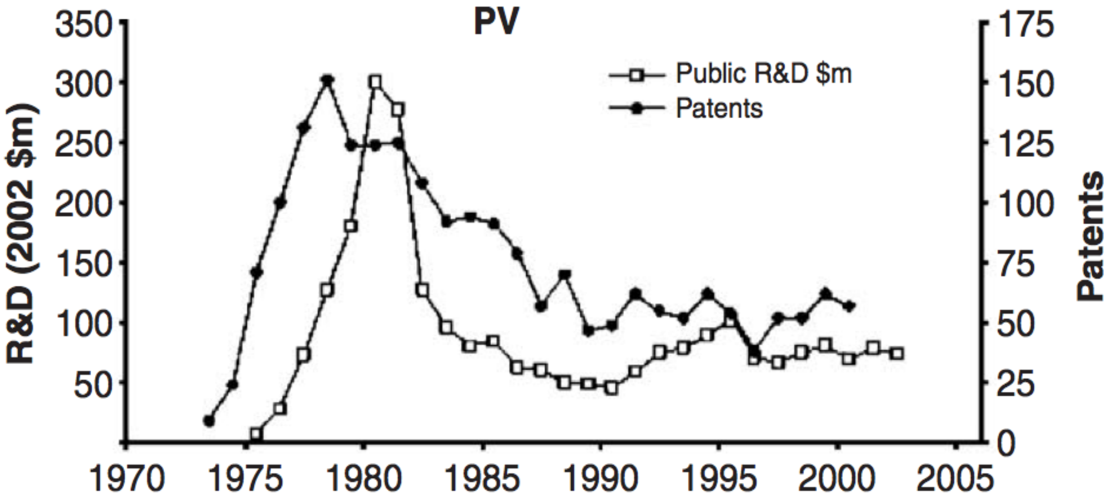
[71] 35 U.S.C. § 200-212.

[72] D.C. Mowery *et al.* (2001), "The Growth of Patenting and Licensing by US Universities: An Assessment of the Effects of the Bayh-Dole Act", *Research Policy 30*: 99-119

[73] G.F. Nemet, D.M. Kammen (2007), "US energy research and development: Declining investment, increasing need, and the feasibility of expansion", *Energy Policy 35*: 764-755

Figure 2.2 PV patents granted for public R&D investments (1970 - 2005).[74]



Source: G.F. Nemet, D.M. Kammen (2007)

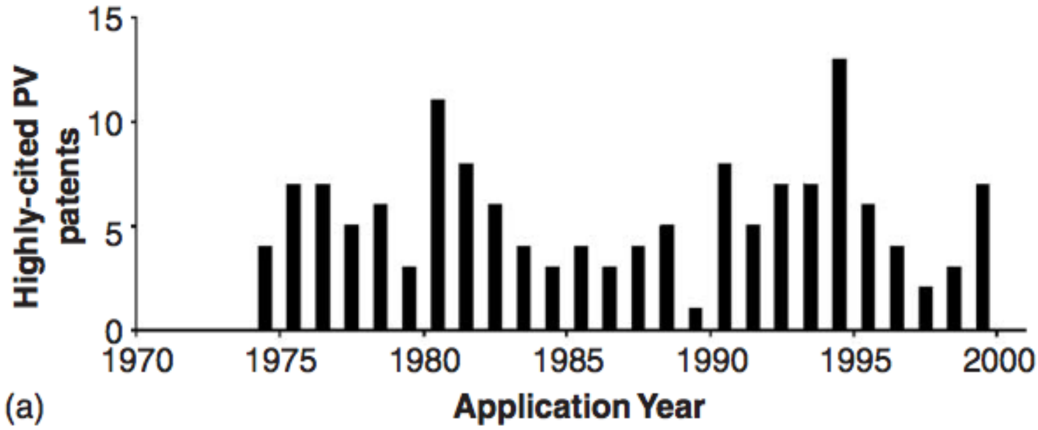
Furthermore, in the case of PV patents journals citation data have been used to identify "high-value" patents, those that received twice as many citations as the average patent in that specific category.[75] Thus, highly cited PV patents can be considered a proxy for "high-value" PV patents.[76] In the energy sector valuable patents do not occur randomly, but they flourish in specific periods of successful innovations and productive public policies, including growing R&D investment (technology-push) and growing demand (market-pull). Therefore, PV patent citations can be used to measure both the return on R&D investment and the health of the commercialization process of that specific technology. This means that the *Bayh-Dole Act of 1980* has been a driver to "high-value" PV patent creation as can be observed in figure 2.3. In the aftermarth of the spike of 1980, disinvestment by the US government in PV energy R&D caused the decline in highly cited PV patents. The same reasoning can be made for the spike in highly cited PV patents of 1994 and the following decline.

[74] Foreign PV patents are excluded by data in the figure. Data include granted patents in the US patent system (USPTO) filed by US inventors only. Patents are dated by their year of application, to remove the 2 years lag average between application and award.

[75] B.H. Hall *et al.* (2001), "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools", NBER, Cambridge, MA.

[76] D. Harhoff *et al.* (1999), "Citation Frequency and the Value of Patented Inventions", *The Review of Economics and Statistics*, vol. 81 (3): 511–515.

Figure 2.3 Highly cited PV patents (1970 – 2000).



Source: G.F. Nemet and D.M. Kammen (2007)

2.2.2 US Solar Energy Policy

This section describes the main energy policies and financial incentives adopted in the United States since the 1970s, and it is subdivided as follows: energy tax credits (Sec. 2.2.2.1), feed-in tariffs (Sec. 2.2.2.2), renewable portfolio standards (Sec. 2.2.2.3), and the loan guarantee program (Sec. 2.2.2.4).

2.2.2.1 Energy Tax Credits

The *Energy Tax Act of 1978*[77] established a 15% residential energy tax credit for solar installations with the objective to shift from fossil fuel supply toward the promotion of renewable energy in response to the unstable energy climate of the 1970s. This credit continued for 8 years until the *Tax Reform Act of 1986* provided for a phased reduction to 12% tax credit. On January 1, 1988 the credit further reduced to 10%. The credit remained at this level until 2005 when the *Energy Policy Act of 2005* created a new commercial and residential "Investment Tax Credit" (hereinafter ITC)[78] for solar energy systems (30% business solar investment tax credit as well as residential solar investment tax credit) that

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[77] Pub. L. 95-618, 92 Stat. 3174 (1978)

[78] ITC may be defined as a reduction of the federal income taxes for individual or businesses that make investments in solar energy generation technology. It is different from the Production Tax Credit (PTC), that not only applies to different technologies, such as wind, but also whose receipt is dependent upon project performance and actual production of energy.

applied for two years from January 1, 2006 through December 31, 2007. Finally, the *Tax Relief and Health Care Act of 2006*[79] extended the energy tax credit for one additional year through December 2008.

The *Energy Policy Act of 2005* also introduced an important stimulus component to solar energy, the "Clean Renewable Energy Bonds" (hereinafter CREBs)[80] authorizing $500 million of those for funding government agencies (state, local, public utilities, and electric cooperatives) in the field of renewable energy projects.[81] Investors receive the tax credit if a qualified issuer uses the bonds to finance a project that is eligible for the renewable energy production credit, including PV projects. The 95% or more of the proceeds of the bonds must be used to finance capital expenditure incurred by qualified borrowers fur such projects. If, within a five-year period, less than 95% of the bonds proceeds are used, the bonds may not qualify as CREBs.[82]

The *Emergency Economic and Stabilization Act of 2008,*[83] passed by the House of Representatives in October 2008, at § 103 extended the 30% ITC for solar energy for additional eight years through December 2016.[84] In particular, at § 106 of Division B of the act (also cited as the *Energy Improvement and Extension Act of 2008),* it is contained an important rule for residential solar investment tax credit that is the elimination of the monetary cap on the tax credit for residential solar electric installations.[85] Finally, the act authorized $800 million of new CREBs to finance facilities that generate electricity from renewable resources, including PV, and extended the termination date for existing CREBs through December 2009.[86]

The *American Recovery and Reinvestment Act of 2009* (hereinafter ARRA) made further progress in the federal tax incentive legislation on PV.[87] A complete new option of *direct cash grants* was added to the Investment Tax Credit. Eligible solar projects are those that come into service before the end of 2017[88], or those that began construction between 2009 and 2010.

[79] Pub. L. No. 109-432, § 201 (2006)

[80] Pub. L. No. 109-58, § 1303 (2005): "Tax credits are provided to holders of clean renewable energy bonds".

[81] See http://www.bakerbotts.com/file_upload/EnergyTaxIncentivesActof2005.htm (available on 15 December, 2009)

[82] M.B. Gerrard, *op. cit.:* 570

[83] Pub. L. No. 110-343 (2008), also known as the Bailout Bill.

[84] After 2016 the solar energy tax credit is not going to expire, but it will be reverted to 10%.

[85] Pub. L. No. 110-343 (2008), Division B, Title I, Energy Production Incentives, Subtitle A, Renewable Energy Incentives, at §106

[86] As of January 2009, CREBs funded a new total of 573 solar projects.

[87] Pub. L. No. 111-5 (2009), also known as Stimulus Bill.

[88] Please note that a different schedule has been given to other technologies: e.g., wind projects need to be placed in service prior to 2013, and other qualified technologies by 2014. Applications must be submitted by October 1,

Cash grants were designed to provide an up-front payment of 30% of the total investment costs and however they were intended for firms making taxable profits, and not at the start-up level. However, for those technologies eligible for the ITC[89] (including PV) the choice was between ITC and a cash grant of the same value.[90] Furthermore, ARRA removed for PV technology the double-dipping penalty, thus allowing projects that elect either ITC or cash grants to also utilize the "subsidized energy financing", for example law-interest loan programs, without suffering a corresponding tax credit basis reduction.

The ITC has some advantages but also a few drawbacks. A disadvantage is the fact that ITC (or the equivalent grant) full credit is realized in the project's first year rather than being spread over time. But because the ITC vests linearly over a 5-year period, the investor must hold on to the project for at least five years in order to realize its value. An advantage of the ITC is that it is not dependent upon project performance and actual production of energy, as the Production Tax Credit would be. Another advantage is that ITC does not require the owner and operator of the project to be the same entity, thus opening the door to a variety of leasing structures.

In conclusion, we can imply two of the main consequences of these federal incentives, whether offered in the form of direct grants or tax incentives. First, they lower the up-front costs of PV projects thus reveling especially important in the case of utility-scale solar power plants, the new frontier of PV power system. Second, since they are not depending upon performance they leave to the solar energy investors a high degree of certainty thus triggering more investments and solar industry growth.

2.2.2.2 Feed-In-Tariffs

Although feed-in tariffs[91] (hereinafter FIT) are widely understood to be a European policy, they originated in a fairly different form in the Unites States under the *Public Utilities*

2011 and the Treasury is required to make payments within 60 days after an application is received or the project is placed in service, whichever is later.

[89] Solar, fuel cells, small wind projects, geothermal, microturbines, and combined heat and power projects. See Section 48 of the Internal Revenue Code of eligible energy projects (IR Code §48).

[90] Cash grant is good in case of economic crisis where revenues are too low for the ITC to be economically sustainable and also for small businesses that cannot use the ITC. Similar to ITC the grant applications must be submitted by October 1, 2011. Payment of grant will be made within 60 days of the grant application date or the date property is placed in service, whichever is later. See Sections 1104 and 1603 of ARRA 2009. Note that under the ARRA, PV projects eligible for the PTC, including PV, have a choice between the PTC and the up-front 30% cash grant. The choice between the two depends on the overall value of the incentives to the project, which differs by technology. The quantitative and qualitative factors that go into this decision are analyzed in M. Bolinger, R. Wiser, K.Cory, T. James, "PTC, ITC, or Cash Grants? An Analysis of the Choice Facing Renewable Power Projects in the United States" Joint projects by LBNL-1642E and NREL/TP-6A2-45359, Golden, CO, NREL, 2009.

[91] A feed-in tariff is a policy mechanism designed to encourage the adoption of renewable energy sources and to help accelerate the move toward grid parity. It typically includes three key provisions: 1) guaranteed grid access;

Regulatory Policies Act of 1978 (hereinafter PURPA). PURPA was passed in the midst of the energy crises that ripped through industrial world economies. Faced with predictions that the price of oil would rise to $100 a barrel, the US Congress acted to reduce dependence on foreign oil, to promote alternative energy sources and energy efficiency, and to diversify the electric power industry. One of the most important effects of the law was to create a market for renewable energy from non-utility power producers. Before PURPA, only utilities could own and operate electric generating plants. PURPA required utilities to buy power from independent companies, the so-called Qualified Facilities, which could produce power for less than what it would have cost for the utility to generate the power, the so-called "avoided cost."

It is worth noting that the current FIT in the United States is a *state and municipal level policy*, and a new FIT at the federal level has never been adopted since PURPA, although it was proposed several times in both Houses of the US Congress. Furthermore, current FIT policies were adopted in the mid-2000s later than in Europe and, therefore, they can be considered as the outcome of lesson learned from successful European states' FIT policies, especially Germany (1991) and Spain (1997).

Two main distinctions need to be made as for the existing FIT methodologies and their sphere of application before describing the approach to FIT in the United States. First, two methodologies exist for setting the overall return that renewable energies developers receive through FIT policies. On the one side, FIT payments are based on the average cost of renewable energy generation, the so-called "*renewable energy project cost-based approach*". On the other hand, they are set on the value of that generation to the utility and on the society.[92] The latter is known as the "*value-based approach"* of setting FIT payments, and it works by estimating the value of the renewable energy either by according it to the utility's avoided costs, or by attempting to internalize the "externality" costs of conventional generation.[93] The value-based approach entails important drawbacks, such as a high degree of administrative complexity, consequent higher transaction costs, and the challenge that the value allocated to renewable energy generation may not match the actual generation costs. The cost-based approach has instead the advantage that FIT payments can be designed to ensure that projects investors obtain a reasonable rate of return. Therefore, if the value-based approach may provide insufficient payments to stimulate rapid market growth, the cost-based approach is more willing to create conditions that are conducive to market growth. The value-

2) long-term contracts for the electricity produced; 3) purchase prices that are methodologically based on the cost of renewable energy generation and tend towards grid parity. Under a feed-in tariff, an obligation is imposed on regional or national electric grid utilities to buy renewable electricity (electricity generated from renewable sources, such as solar power, wind power, wave and tidal power, biomass, hydropower and geothermal power), from all eligible participants. Source: Wikipedia

[92] K. Cory, T. Couture, C. Kreycik (2009), "Feed-In Tariff Policy: Design, Implementation, and RPS Policy Interactions", NREL/Technical Report-6A2-45549, March: 2

[93] Including: putting a value for climate mitigation; health and air quality impacts; effects on the energy security. A. Klein *et al.* (2008), "Evaluation of different Feed-In Tariff Design Options – Best practice paper for the International Feed-in Cooperation", BMU, October, 2nd ed.

based approach is the one mainly adopted in the United States, and so far resulted unsuccessful at driving rapid growth in PV energy, whereas the cost-based approach has been adopted extensively and successfully by European FIT policies.[94]

Another important distinction is that between *utility-based* and *state-level FIT policies*. State-level FIT policy is mandated at the state level and requires utilities operating within their jurisdiction to purchase electricity generated from renewable energy sources. Whereas utility-based FIT policy is when one or more utilities operating in a state choose to implement their own FIT policies to help meet utility-specific goals, which may range from meeting renewable portfolio standard targets to encouraging distributed generation.

According to National Renewable Energy Laboratory (NREL) statistics, as of April 2009: one state had enacted state-level FIT legislation based on avoided cost: California (Section 2.3.1); one state had implemented utility-specific premium price FIT policy[95]: Vermont; three states had enacted utility-based FIT: Oregon, Washington, and Wisconsin; and six states as well as three municipalities[96] had proposed renewable energy cost-based FIT legislation: Michigan, Rhode Island, Hawaii, Minnesota, Illinois, and Indiana. Nonetheless, the first case of a US cost-based FIT for solar PV was the city of Gainesville in Florida, whose City Commission approved at the beginning of 2009 a utility-level's proposal of a FIT policy tailored to solar PV. This policy is unique in the United States as it is the first FIT to be based on the average cost of generating electricity from RE sources, with an estimated rate of return, thereby making it close in design to FIT policies in Europe. Although this policy had been modeled after Germany's FIT, it was implemented at the municipal level rather than the state level. FIT payments would be awarded for a period of 20 years and they were designed to decrease by approximately 5% beginning in 2010 following a digression rate. The fixed rate for the life of the contract would start at \$0.32/KWh or \$0.26/KWh depending on size and application, before they decrease over time. Additionally, the program included an annual program cap so that no more than 4 MW of new installed solar capacity would be installed in any one year. Table 2.1 summarizes the existing FIT programs applying to PV technology in the United States.[97]

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[94] Cory *et al.* (2009), *op. cit.*: 2-3. As of February 2009, no US states have implemented FITs based on the RE project cost. Gainesville Regional Utility in Florida, has approved the first US cost-based FIT for solar PV.

[95] This policy offers a bonus, or premium, above the average avoided cost price.

[96] Los Angeles (CA), Santa Monica (CA), Palm Desert (CA).

[97] http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=FL77F&re=1&ee=0 Accessed January 2011.

Table 2.1 FIT Programs for PV in the United States (as of April 2009).

State	***Utility***	***FIT Type***	***Price (c/KWh)***	***Contract Duration***	***Project Size Caps***	***Program Size Caps***
California	All investor-owned utilities	Avoided-cost based	6 to about 20	10, 15, or 20 years	1.5 MW	478 MW
Florida	Gainesville Regional Utilities	Cost of generation based	32	20 years	None	4 MW
Oregon	Eugene Water & Electric Board	Utility based fixed-price incentive	12	10 years	Only projects >10 KW	None
Vermont	Green Mountain Power	Fixed-price incentive plus premium price	6	Unspecified	250 KW	None
Washington	Almost all (60+)	Utility based fixed-price incentive	15-54	Until June 2020	N/A	N/A
Wisconsin	Madison Gas & Electric	Utility based fixed-price incentive	25	10 years	1-10 KW	300 KW

Source: Couture & Cory (May 2009) NREL

2.2.2.3 Renewable Portfolio Standards

We define renewable portfolio standards the requirement that retail electricity suppliers or utilities procure a certain minimum quantity of eligible renewable energy or capacity, measured in either absolute units (KWh or KW) or as a percentage share of retail sales. Renewable portfolio standards policies (hereinafter RPS) have been designed to maintain and/or increase the contribution of renewable energy to the electricity supply mix. They establish numeric targets for renewable energy supply and seek to encourage competition among renewable developers to meet the targets in a least-cost approach.

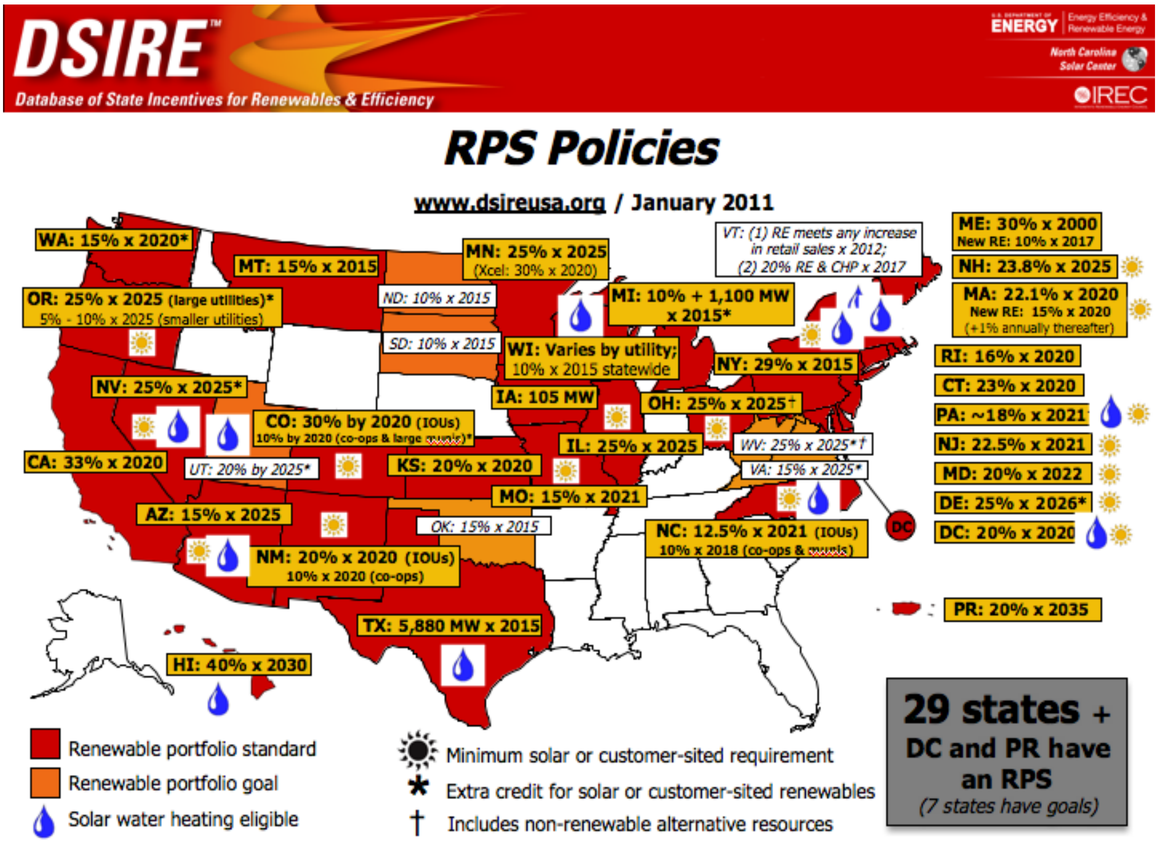
RPS is a mandatory policy and can be listed within the environmental policies as a command-and-control regulation. It is a state-level policy since it is not implemented at the federal level and it is quite a recent policy that started only in late 1990s. RPS policy designs vary widely among states, and a common design has not yet emerged. One important structural difference among state RPS policies relates to how compliance is achieved. Three distinct RPS compliance models have been adopted so far. First, in states with retail electric competition, electricity suppliers are typically given broad latitude to comply with RPS requirements. Second, in states with still-regulated utility monopolies, electricity regulators oversee utility procurement and contracting under the RPS. Two states make an exception, New York and Illinois, where a state agency has direct responsibility to conduct procurements under the RPS.[98]

As of January 2011, 29 states and Washington D.C. and Puerto Rico have a mandatory RPS. Besides mandatory RPS, seven other states created non-binding renewable energy goals through legislative action (Fig. 2.4). Most state RPS policies have been established by legislative action, whereas two states (New York and Arizona) developed their programs through regulatory channels, and two other states (Washington and Colorado) did so via voter-approved ballot initiatives.

[98] R.Wiser, G. Barbose (2008). “Renewables Portfolio Standards in the United States. A status report with data through 2007”, Lawrence Berkeley National Laboratory, Report no. 154. April 25: 6-7

(http://eetd.lbl.gov/ea/ems/re-pubs.html).

Figure 2.4 Distribution of RPS in the United States and California.



Source: DSIRE, January 2011

There is not a universal agreement about eligible resources and the generic term renewable is used to describe RPS policies. Certainly, renewable energy sources are typically eligible to meet RPS obligation in states where such resource is available. As already observed, RPS is only a state-level initiative, though several attempts were made at the federal level to reach a national RPS standard. The US Congress considered a number of federal RPS proposals in the House of Representatives and the Senate, but to date, no proposal has passed both houses.

One key element that needs to be addressed is how such a federal standard might interact with the pre-existing state RPS policies. First, under preemption doctrine rooted in the Supremacy Clause[99] of the US Constitution a state law that conflicts with a Federal statute is invalid.[100]

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[99] The US Supremacy Clause provides: "This Constitution, and the Laws of the United States which shall be made in Pursuance thereof; and all Treaties made, or which shall be made, under the authority of the United States, shall be the Supreme Law of the Land; and the Judges in every States shall be bound thereby, any Thing in the Constitution or Laws of any State to the Contrary not withstanding". See the US Constitution art. VI, § 2.

[100] The preemption doctrine contrasts with the EU's subsidiarity principle.

Furthermore, "ceiling preemption", i.e. the federal regulatory scheme is so detailed and pervasive to preclude adoption of additional, more protective regulatory choices by state and local governments, is different from "floor preemption", i.e. the Federal government creates a minimum standard and state and local governments can impose more stringent regulatory requirements and adopt stricter standards.[101] Finally, a third case of pre-emption can apply, the often called "field preemption", in cases when the Congress has completely foreclosed state action in a particular area.[102]

Buzbee claims benefits from federalism's institutional diversity:

> "Federal floors create incentives and markets for pragmatic improvement, and innovation that will seldom exist with Federal regulatory ceilings. (…). Legislative and regulatory debate over climate change legislation has explicitly confronted the floor/ceiling choice, with previously resistant industry tentatively indicating support for climate change legislation dealing with GHGs provided Federal law would preclude disparate or additional state and local regulation."[103]

Industry has reacted to the costs of disparate states' regulation with calls for preemptive federal law. Industry has also secured preemptive federal law when federal law or regulations require either particular product design or substantial production investment benefiting from economies of scale. This is most notably true in motor vehicle pollution regulation under the Clean Air Act, where federal emission limitations are set, and states are precluded from precluding additional standards of their own. California makes an exception to this ceiling preemption and is allowed to adopt strongest measures to tackle GHGs emissions, thus making this less than a completely preemptive federal area of law. Although, industry's support for ceiling preemption is motivated by the desire for a federal legislative fix preempting any state or local regulation of activities emitting GHGs, far more common are federal laws that set floors and allow greater state or local stringency in the adoption of regulations. Thus, if we add that cooperative Federalism schemes are especially prevalent in the environmental law field, where through a vast array of statutorily created incentives, state

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[101] W.W. Buzbee (2009), "Federal Floors, ceilings, and the Benefits of Federalism's Institutional Diversity" in *Preemption Choice: The Theory, Law and Reality of Federalism's Core Question,* Cambridge University Press, Cambridge, NY: 98-115

[102] D.A. Farber (2009), "Legal Guidelines for Cooperation between the European Union and American State Governments". Farber is Professor of Law at the University of California at Berkeley, Chair of the Energy and Resources Group (ERG), and Director of the newly established UCB Climate Energy Policy Institute (CEPI).

[103] Buzbee (2009), *op cit:* 99

and local actors will assume critically important regulatory duties[104], we can conclude that in case of adoption of a federal RPS it is more reasonable that preemptive ceilings will not apply and those states, like the State of California, having higher RPS standards will be able to keep them in case federal RPS would be lower.

The issue of "double-counting" of credits is a very complicated issue and it has not been addressed comprehensively in most state-level RPS policies. Most states for instance address "double-counting" of credits in their RPS policies with the aim of rejecting the same credits from being used to satisfy more than one RPS requirement. Other states prefer to consider "double-counting" restrictions as specified against another state's program, whereas others prohibit the practice of "double-counting" with respect to any other jurisdiction".[105] Whether these restrictions are intended to restrict an electricity provider from using its state RPS purchases towards a possible future federal RPS is unclear.[106] In conclusion, in our opinion the issue of interactions between state RPS and a federal RPS should be addressed shortly and before a federal RPS is taken into consideration for adoption.

2.2.2.4 The Loan Guarantee Program

The loan guarantee program was born as an incentive policy applying to "innovative" commercial technologies and lays its foundation in Title XVII of the *Energy Policy Act of 2005* (hereinafter EPAct 2005)[107]. A loan guarantee is a contractual obligation between the government, private creditors and a borrower, such as banks and other commercial loan institutions, that the Federal Government will cover the borrower's debt obligation in the event that the borrower defaults. The Loan Programs allow the Federal Government to share some of the financial risks of projects that employ new technologies that are not yet supported in the commercial marketplace or where private investment has been inhibited. This federal program appears to be very important in the PV energy field, where expansive and risky investments need to be made in order to start a PV project.

Section 1703 of the EPAct 2005 on "Eligible Projects" authorized the U.S. Department of Energy (DOE) to issue loan guarantees for projects that "avoid, reduce or sequester air pollutants or anthropogenic emissions of greenhouse gases; and employ *new or significantly improved technologies* as compared to commercial technologies in service in the United States at the time the guarantee is issued."[108] As for categories of projects eligible for a

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[104] *Op. cit.:* 101

[105] R. Wiser *et al.* (2007), "Renewable Portfolio Standards: A factual introduction to experience from the United States", LBNL-62569: 14

[106] Colorado is the only state addressing Federal RPS interactions in its RPS policy. It allows double-counting of credits.

[107] Pub. L. No. 109-58 (2005). See § 1701-1704 for incentives for innovative technologies.

[108] See § 1703 "Eligible Projects" of Pub. L. No. 109-58 (2005).

guarantee there are, among others, renewable energy systems, including PV.[109] As for the amount of the guarantee, it shall not exceed an amount equal to 80% of the project cost of the facility that is subject of the guarantee, as estimated at the time at which the guarantee is issued.[110] In exchange for the loan guarantee DOE should receive either an appropriation for the subsidy cost or payment of that cost in full by the borrower. The guarantee should have a "reasonable prospect of repayment" of the principal and interest on the obligation by the borrower, who on his side should take into serious consideration the calculus of the credit subsidy cost. In fact, this is the net present value at the time the loan guarantee is executed of the expected payments of the US government to cover defaults, fees, interest subsidies and other payments resulting from the loan guarantee provided under the program.[111] Actually, no funds have been appropriated for the subsidy cost of loan guarantees under the first solicitation, and the borrowers approved to receive loan guarantees by paying the full cost.[112] It is worth noting that under the original authorization, loan guarantees were intended to encourage early commercial use of new or significantly improved technologies in energy projects. Therefore, it did not support RD&D projects, nor technology that were already in commercial use in the United States.

In 2009, ARRA extended the authority of the DOE to issue loan guarantees and appropriated $6 billion for this program.[113] Under this act, the DOE may enter into temporary guarantees if the project starts by September 30, 2011. ARRA amended EPAct 2005 by adding a new section defining eligible technologies for new loan guarantees. Eligible projects include renewable energy projects that generate electricity (or thermal energy), and commercial projects that manufacture related components for renewable energy projects.[114]

The most important difference between the loan guarantee eligibility regulations contained at § 1703 of Title XVII of EPAct 2005, and the ones contained at § 1705, which was added to the EPAct by the ARRA, is that this last has dropped the requirement for innovative technology.

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[109] Other eligible technologies are: advanced fossil energy technology, hydrogen fuel cell technology, advanced nuclear energy facilities, carbon capture and sequestration technologies, efficient end-use energy technologies, pollution control equipment, refineries, efficient electrical generation transmission and distribution technologies.

[110] Loan Guarantee Program focuses on projects with total project costs over $25 million.

[111] See § 1702 "Terms and Conditions" of Pub. L. No. 109-58 (2005).

[112] The loan guarantee program was authorized to offer more than $10 billion in loan guarantees for renewable energy, energy efficiency, advanced transmission and distribution projects.

[113] Supporting guaranteed financing from $60 billion to $120 billion.

[114] It also included projects in the electric power transmission systems, as well as innovative biofuels projects. Funding for biofuels projects is limited to $500 million.

2.3 State-Level Solar Energy Policies in the United States: the Case of California

US state governments also play an important role in the RD&D and deployment of advanced energy technologies. In recent years, state governments have spent as much in energy programs as DOE spent on energy RD&D on Basic Energy Science combined mainly on renewable energy and energy efficiency demonstration and commercialization programs. Nevertheless, states contributions to energy-related goals should ensure that DOE coordinates with the states and they cannot be considered as substitutes for a coordinated national energy RD&D strategy.[115]

As far as state energy policy is concerned, we will take California as our case study, for its progressive policies and regulations aimed at the promotion of electricity generation from solar energy sources. In particular, these policies are: the renewable portfolio standard (Sec. 2.3.1), the feed-in tariff (Sec. 2.3.2), the net metering program (Sec. 2.3.3), and the California Solar Initiative (Sec. 2.3.4).

2.3.1 The Renewable Portfolio Standard

California's RPS is considered as one of the most aggressive in the United States. It adopts the compliance model according to which all retail sellers of electricity (public or private utilities) shall serve 20% of their load with renewable energy by 2010 and 33% by 2020. However, California has set a general renewable energy target, and it did not decided on a specific target for solar energy and PV power.

When California's RPS was originally established in 2002 (*Senate Bill 1078)* the target was 20% of electricity produced from renewable energy by 2017. In 2006 the same target but with a more stringent time constraint was adopted with a requirement of a minimum of 20% by 2010 (*Senate Bill 107).* The new targets have been settled through an *Executive Order no. S-21-09*[116] adopted on September 15, 2009.

The fact that the governor of California has adopted the new RPS policy by an Executive Order, which is a regulatory and not a state legislative tool, raises questions as whether a state

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[115] L.d. Anadon *et al.* (2009), "Tackling US energy challenges and opportunities", Energy Technology Innovation and Policy Group, Belfer Center for Science and International Affairs, Harvard Kennedy School, February: 3-4

[116] http://gov.ca.gov/executive-order/13269. It was preceded by *Executive Order no. S-14-08* issued on November 17, 2008, establishing the same targets.

governor can contradict existing law, or just implement and extend it, through an Executive Order. Prior to the Executive Order the California Public Utility Commission (CPUC) and the California Energy Commission (CEC) were responsible for implementing and overseeing the RPS. On the other hand, the Executive Order shifted the responsibility to the California Air Resources Board (CARB), a state agency, which is required by the current law, *A.B. 32* of 2006, to regulate sources of greenhouse gasses to meet a state's goal of reducing greenhouse gas emissions to 1990 levels by 2020, and an 80% reduction of 1990 levels by 2050.[117] Although CEC and CPUC continue their implementation and administration of the 20% requirements, the CARB is authorized to increase the target and accelerate and expand the time frame. This means that the evolution of the RPS policies in California stands in the hands of the governor through its state agency.

By issuing an Executive Order to regulate RPS the governor of California explicitly decided to veto state legislations (*S.B. no. 14* and *A.B. no. 64)*[118], on the base of his dissatisfaction with the final bill language and the lack of a regional approach of both the provisions. He acted by maintaining that the legislative package on RPS adds new regulatory hurdles to permitting renewable resources in the state, at the same time limiting the import of cost-effective renewable energy from other states in the West. In his veto statements he calls for the foundation of a "regional effort that optimizes resources throughout the West at a lower cost to ratepayers".[119]

According to Weissman of UC Berkeley,[120] vetoing state legislative bills would leave the statutory standard at 20%.[121] Furthermore, what the governor creates through one Executive Order, he could destroy with another without needing any legislative action. Nevertheless, Weissman asserts that there are counter-arguments that apply here. First, increasing access to out-of-state projects can help meet ambitious renewables standards. Second, an agency such as the California Air Resource Board could potentially implement an Executive Order more quickly than a new law. "The California Air Resource Board's mandate under climate change legislation may be broad enough to justify its direct role in implementing a 33% standard. However, it is quite likely that the governor's approach will increase uncertainty".[122] It is indeed true that with this grade of legal and political uncertainty, the renewable energy industry may lack the stable regulatory environment that is essential for its growth. Of the same advice is Farber of UC Berkeley, who objects that since the Executive Order calls for

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[117] California Global Warming Solutions Act of 2006, or Assembly Bill 32, is one of the most advanced emissions cap regulation in the United States. See at http://info.sen.ca.gov/cgi-bin/statquery

[118] SB No. 14 and AB No. 64 passed the Senate and Assembly and were thus both ready for governor's signature.

[119] Arnold Schwarzenegger's veto statements to S.B. No. 14 and A.B. No. 64, issued on 10/12/2009.

[120] Associate Director for Energy Law and Policy of University of California Berkeley Center for Law, Energy and the Environment, and former judge at the California Public Utility Commission.

[121] Author interview with Steven Weissman, March 19, 2010, UC Berkeley.

[122] S. Weissman (2009), "For renewable energy in California, it is not sure which way the wind is blowing", www.legalplanet.wordpress.com accessed September 2009.

the same RPS targets, then it shouldn't be considered as legally binding because of inconsistency with RPS state legislation.[123]

According to the Third Quarter 2010 Report by the CPUC, the California Investor-Owned Utilities collectively served 15.4% of their 2009 electric load with renewable energy under the RPS program corresponding to more than 1,000 MW capacity, and up from 13% in 2008.[124]

In conclusion, from our analysis of the California's renewable portfolio standard program we believe that this constitutes one of the main drivers for its PV industry growth. Although to qualify for the RPS the electricity needs either to be produced in-state, or produced out-of-state and delivered into the state, the most of renewable electricity comes from photovoltaic facilities developed by California's companies, therefore making the Golden State one of the world leader in PV energy development.

2.3.2 The Feed-In Tariff

In the early 1980s, California played a leading role in developing a federal feed-in tariff and it became the state to most aggressively implement PURPA. As to give an example, Standard Offer Contract (SOC)[125] No. 4 helped to encourage the development of almost 1,200 MW of wind power in California between 1984 and 1994. However PURPA was based on the notion of utility "avoided costs," and contracts in California were locked in based on projections of the long-run price of natural gas.[126] When actual natural gas prices dropped well below the projections, SOCs payments kept rising and proved too costly to the ratepayer, thus giving PURPA a negative connotation that still persists in the United States.[127]

Nevertheless, current FIT policy in California is different from federal FIT under PURPA in that it is updated annually, and it is also more closely tied to current utility avoided cost, unlike California's SOC No. 4, which was pre-determined at the beginning of the contract, based on projections of the long-run avoided cost. California's FIT policy was passed into law by *Assembly Bill 1969* in September 2006 (hereinafter A.B. 1969)[128]. AB 1969 required

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[123] Author interviews with Daniel Farber, October and November 2009, UC Berkeley.

[124] CPUC (2010c), "Renewables Portfolio Standard", Quarterly Report, 3rd Quarter 2010.

[125] "Standard Offer Contract (SOC)" has sometimes been used interchangeably with "Feed-In Tariff". It is important to distinguish modern cost-based FIT policies, which are often highly differentiated in their design and overall payment structure, from previous SOCs, which were based on varying interpretations of the notion of avoided cost.

[126] Avoided costs are estimated by location and depend on the marginal electricity resources for that location. In some states, this could have been based on natural gas, oil, or nuclear. In Calfornia, the avoided cost is the amount the utility would have incurred to build new gas-fired generation but for the existence of the QFs.

[127] These up-front subsidies range from $1.55/watt to $2.30/watt as of October 2008. CPUC, Staff Progress report", CPUC California Solar Initiative (CSI), http://gosolarcalifornia.org/documents/csi.html

[128] Assembly Bill No. 1969, http://info.sen.ca.gov

utilities to file a standard tariff for the purchase of renewable electricity from a number of eligible renewable energy resources, including PV.[129] The FIT was here envisaged for systems with a limit on individual project size capacity of 1.5 MW, capped at 250 MW total statewide. The tariff payment level was determined according to the market price referent (MPR)[130] at the time of commercial operation of the plant; it is fixed at this level over a period of 10, 15, or 20 years.[131]

The original FIT program as it was conceived in A.B. 1969 was limited to plants sited at wastewater and water treatment facilities, but the CPUC through resolution E-4137[132] extended the program to apply to all Investor-Owned Utilities (IOUs) and expanded the total program size cap to 478 MW. Finally, in October 2009 Senate Bill 32[133] amended the feed-in tariff legislation by elevating both the statewide program cap to 750 MW cumulative capacity of installed generation and the project size to 3 MW (Tab. 2.2). The new law took effect January 1, 2010, but the amendments will not be incorporated into the actual program until the California Public Utilities Commission (CPUC) develops regulations to implement the program changes.

The CPUC specifies that the tariffs are to be adjusted according to the time of delivery, differentiated as either peak, shoulder, or off-peak, and are to differ depending on whether the electricity is supplied in the summer or winter, and by which utility. This MPR approach means that California's FIT policy is based on avoided-costs, as opposed to one based on the levelized cost of renewable energy generation as, we will see, it is the case of German feed-in tariffs.

In conclusion, the FIT policy has had little impact on California electricity generation from PV sources so far. This is largely due to three main reasons, the first of which is legal. In the feed-in tariff system, the utility could be considered a wholesale seller and wholesale electricity transactions can be regulated only by the federal government (FERC). So California, as other US states, have been afraid of legal challenges if they use feed-in tariffs. Second, the suite of rebates and up-front subsidies is not available to PV technologies under the FIT policy. Approximately 97% of developers and residents opt for the high up-front rebates available under the California Solar Initiative or the net metering program instead of

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[129] "The program requires that a retail seller of electricity, including electrical corporations, community choice aggregators, and electric service providers, but not including local publicly owned electric utilities, purchase a specified minimum percentage of electricity generated by eligible renewable energy resources, as defined, in any given year as a specified percentage of total kilowatthours sold to retail end-use customers each calendar year (renewables portfolio standard)".

[130] The MPR is the anticipated average annual cost of generation from the power plant that would otherwise be supplying the load in that area, making it a slightly more nuanced form of the avoided cost payments previously awarded under California's SOC No. 4. The MPR in California is determined by the market price of natural gas.

[131] AB 1969, ph. (d): "The tariff shall provide for payment for every kilowatt-hour of renewable energy output produced at an electric generation facility at the market price (…), for a period of 10, 15, or 20 years (…)".

[132] http://docs.cpuc.ca.gov/PUBLISHED/AGENDA_RESOLUTION/78711.htm

[133] http://info.sen.ca.gov

the FIT payment due to their higher rate of return.[134] Third, the price of electricity in California is already higher than the average in the United States, and therefore consumers are not willing to bear the burden of an even higher price and therefore opt for other programs.

From table 2.2 we can notice how it would be necessary that S.B. 32 be implemented in order to make the California's feed-in tariff policy a more effective driver for solar generation, and consequently for PV industry growth in the Golden State.

Table 2.2 The feed-in tariff legislation in California.

	Utility	*FIT Type*	*Technology Eligible**	*Contract Duration*	*Project Size Caps*	*Program Size Cap*
AB 1969	Wastewater and Water Treatment Facilities	Avoided-cost based	PV (and other renewables)	10, 15, 20 years	1.5 MW	250 MW
E-4137	IOUs only	Avoided-cost based	PV (and other renewables)	10, 15, 20 years	1.5 MW	478 MW
SB 32	IOUs and POUs	Avoided-cost based	PV (and other renewables)	10, 15, 20 years	3 MW	750 MW

*Participants to FIT program with PV technology systems, may not simultaneously obtain benefits from the FIT and the California Solar Initiative, or the net metering program.

[134] S.B. No. 32, § 3 and § 3.5, Ph. (k) 3

2.3.3 The Net Metering Program

Net metering has become a widespread policy in the United States for supporting distributed generation PV adoption. In California, the net metering policy took effect in 1996 and allowed commercial, industrial, residential and agricultural customers to generate their own electricity from PV and place the excess power back into the grid and net out charges for power taken off of the grid. This incentive policy that looks more like a subsidy has contributed to the diffusion of small-scale on-grid solar PV systems and therefore it can be considered as one of the main drivers to PV growth in California.[135]

The California's legislative act regulating net metering was followed in 2009 by *Assembly Bill 920* (hereinafter A.B. 920).[136] This act was innovative because it allowed private owners of renewable energy systems to sell any net excess electricity generated over the course of twelve months and get back the net surplus compensation. Since the enactment of A.B. 920, the California net-metering system gave two options to consumers on how to obtain this surplus compensation: by carrying forward their bill credit for any net-excess generation, or by receiving net surplus electricity as a credit for KWh.

A further legislation enacted in 2006 (S.B. 1) increased the aggregate limit of net-metered systems in a utility's service territory from 0.5% to 2.5% of the utility's aggregate customer peak demand. Finally, in February 2010 a new piece of legislation was enacted (A.B. 510*)* that would require that the tariff for net energy metering be offered on a first-come-first-served basis until the time that the total rated generating capacity used by eligible customer-generators exceeds 5% of the electric utility's aggregate customer peak demand.

All California's Investor-Owned Utilities (IOUs), PG&E, SDG&E, and SCE, offer net metering to residential customers with PV systems. In addition, California net metering regulates that Publicly Owned Utilities (POUs) may elect to provide co-energy metering, which is the same as net metering, but incorporates a time-of-use rate schedule. Customer-generators with systems sized between 10 KW and 1 MW who are subject to time-of-use rates are entitled to deliver electricity back to the system for the same time-of-use (including real-time) price that they pay for power purchases. Time-of-use rates can work well with net metering, particularly if the PV system produces excess electricity during peak periods - the time of day when the highest rates are charged for electricity (net metering customers who produce excess electricity during those periods will receive the highest credits).

The vast majority of solar PV customer-generators choose to be on a net metering tariff and by the end of 2008 over 40,000 residential and 3,000 non-residential customers from the three

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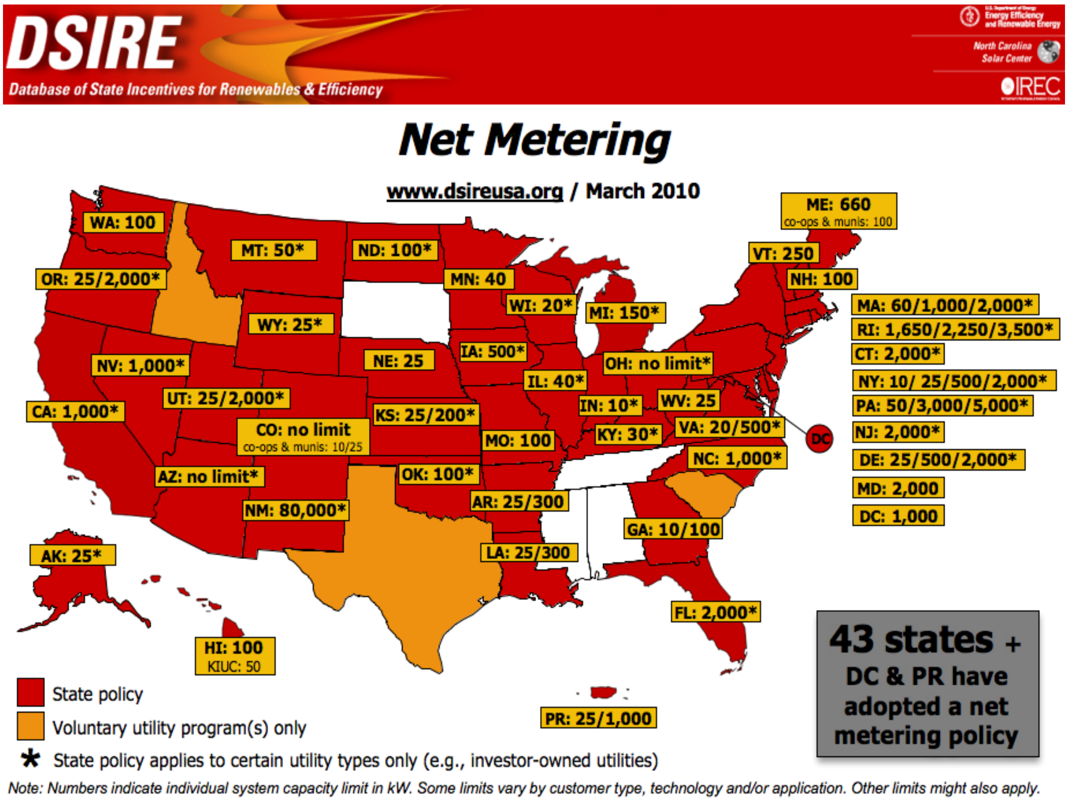
[135] N. Darghouth, G. Barbose, R. Wiser (2010), "The Impact of Rate Design and Net Metering on the Bill Savings from Distributed PV for Residential Customers in California", LBNL-3276E

[136] AB 920 was signed by the governor of California on October 11, 2009.

IOUs enrolled in California's net metering program.[137] Before concluding, it is worth noting that these accounts and the electricity generated under net metering do not count toward meeting each California utility’s RPS obligation.[138]

Figure 2.5 illustrates net-metering systems in the United States as of March 2010. It can be observed that 43 states plus Washington DC and Puerto Rico offer net metering as a state policy. Other three states have a voluntary utility program only.

Figure 2.5 Net metering policies in the United States and California.



Source: DSIRE, March 2010

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[137] Only 245 solar PV accounts representing 3MW of generating capacity opted to not take the net metering tariffs (as of September 2009).

[138] CPUC (2010a).

2.3.4 The California Solar Initiative

California's *Senate Bill 1* (hereinafter S.B. 1)[139] of August 2006 is one of the most effective pieces of legislation adopted in California for the fostering of a robust PV industry.

The first characteristic of S.B. 1 was directing the CPUC to fund a state rebate program to reward consumers for installing solar energy systems, known as the California Solar Initiative (hereinafter CSI).[140] The second feature was the requirement that a developer of more than 50 new single family homes in a single subdivision include photovoltaics as a standard option beginning January 1, 2011, making it easy for homebuyers to take advantage of this clean energy source. A third aspect was that before the adoption of S.B. 1 only investor-owned utilities were required to have solar programs, while municipal utilities were not. Now, the bill requires also municipal utilities (or public owned utilities, POUs) to establish programs supporting the CSI.

The CIS program is only one part of a broader solar effort in California, branded collectively as the "*Go Solar, California!"* campaign or "*Million Solar Roofs Plan*"[141]. This entailed a State of California investment of $3.3 billion ratepayer-funded effort to install 3,000 MW of new grid-connected solar over the next decade. The aim of this campaign, launched in January 2007, was to transform the market for solar energy and make it closer to the grid parity with conventional energy sources by reducing the cost of solar. The CSI portion of the Plan, the country's largest solar program, aimed at driving small size PV installations of 1,940 MW over 10 years, by the end of 2016, requiring investments for $2.2 billion in incentives to consumers (residential and non-residential) who install solar electric systems. CSI applies to *existing* residential homes and *existing and new* commercial, industrial, and agricultural properties.

The second *Million Solar Roofs Plan's* component that has been contributing to the growth of California solar installations is the "New Solar Homes Partnership" (hereinafter NSHP).[142] There are two main differences between CSI and NSHP. The first is that whereas the CIS is supporting solar installation on *existing* homes, the NSHP is focused on installations on *new* homes. The second difference is that the CIS is launched and managed by the CPUC, whereas the NSHP is managed by the CEC. In the framework of the NSHP, CEC will manage a 10-year $350 million program to encourage 400 MW of solar installations in *new* home construction, allowing builders that integrate solar photovoltaic electricity systems (BIPV) in

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[139] Available at http://info.sen.ca.gov/pub/05-06/bill/sen/sb_0001-0050/sb_1_bill_20060821_chaptered.html

[140] See D.06-01-024 (the "January CSI Decision"). Through the California Solar Initiative, the Public Utility Commission and CEC endeavor to transform the existing energy market to make solar products cost-effective, with the goal of eliminating the need for incentive payments after 2016.

http://docs.cpuc.ca.gov/published/Final_decision/52898.htm

[141] www.GoSolarCalifornia.ca.gov

[142] http://www.gosolarcalifornia.ca.gov/nshp/

California to be eligible to participate and receive financial incentives. The third program, other than CSI and NSHP, is a set of solar programs offered through publicly-owned utilities (POUs) that are not regulated by the CPUC.

CSI offers performance-based incentives for solar energy systems greater than 100 MW in size, installed in businesses and other large facilities. On the other hand, for systems smaller than 100 MW incentives for residential and small businesses will be based on each system's estimated future performance.[143] Both mechanisms reward the selection and proper installation of high quality solar systems.[144]

With the aim to reach high quality solar systems, in September 2007 the CPUC made a decision establishing a Research, Development, Demonstration and Deployment Plan for the California Solar Initiative.[145] The decision adopted a plan for rewarding $50 million in the form of grants to RD&D projects under the CSI program. As the CSI program runs through 2016, the adopted CSI RD&D Plan also runs through 2016 and it is preparing a shift from an incentive-based program to a self-sustaining solar market in the years beyond. If it is true that solar PV starts to be competitive at the large-scale level, it is not yet at the small-scale residential level.

To establish a robust portfolio of RD&D projects, the funds will be allocated across all stages of RD&D[146] with a relatively greater emphasis on demonstration. Research will receive 20% of the RD&D budget while development and deployment will receive each between 5-10%, and demonstration will be given 45-55% of the RD&D budget. RD&D funds will also be allocated across three high priority target activity areas identified in the CEC's Public Interest Energy Research RD&D process: support the commercialization of new photovoltaic technologies; improve the integration of PV with the distribution and transmission grid; and focus on approaches to support the market and end-users.

Figure 2.6 shows the trend for capacity installed by month over the course of the CSI program, from its onset in 2006 through 2010, in both the residential and non-residential sectors.

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[143] "ALJ's Ruling Requesting Comment on Staff Proposal for Performance Based Incentives and Other Elements of the California Solar Initiative", April 25, 2006.

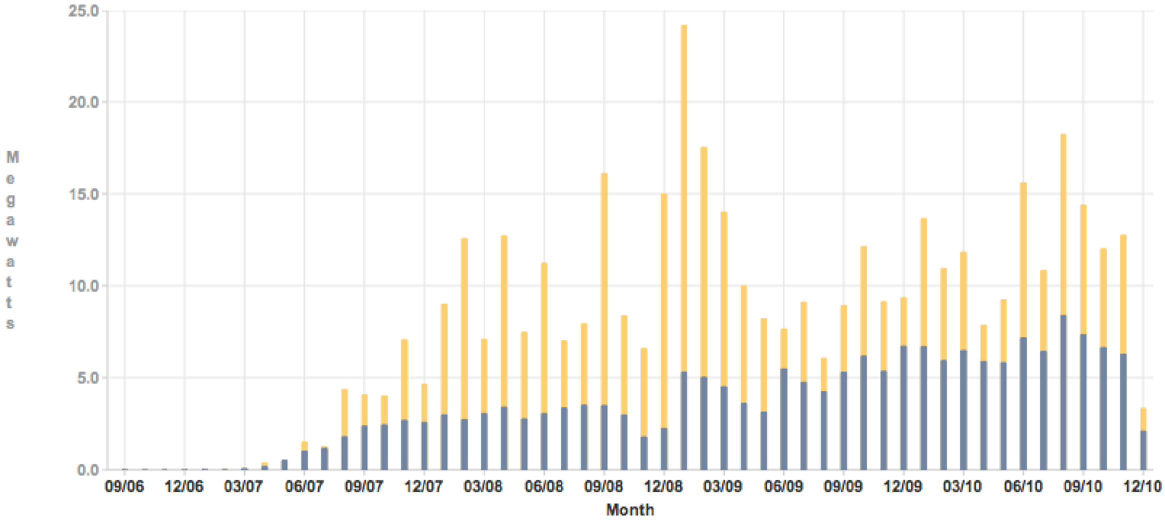
http://docs.cpuc.ca.gov/published/comment_decision/58770-01.htm

[144] *PV Status Report 2009*, European Commission JRC: 55

[145] D.07-09-042 of September 20, 2007. The RD&D program will focus on: improve the economics of solar technologies by reducing technology costs and increasing system performance; provide bridge funding to help promising solar technologies transition from a pre-commercial state to full commercial viability; fill knowledge gaps to enable successful, wide-scale deployment of solar distributed generation technologies; overcome significant barriers to technology adoption

[146] See the Adopted CSI RD&D Plan, Appendix A. Deployment is an element of demonstration as that term is used in Pub. Util. Code § 2851(c)(1).

Figure 2.6 CSI installed applications from the beginning of CSI program (2006-2010)



Source: www.CaliforniasolarStatistics.ca.gov

Legend:

Yellow: non-residential installations

Blue: residential installations

2.4 Solar Energy and Technology Policies in the European Union

In sections 2.4.1 and 2.4.2 we briefly introduce the main European Union legislation in the field of renewable and more specific solar energy and technology policies in order to give a framework to next section 2.5, where Germany's solar energy and technology policies will be taken as a case study. Germany took the lead in Europe in the renewable energy, and in particular in the photovoltaic field, thanks to the introduction of a feed-in tariff law that certainly constitutes the most important driver to the development of the German PV industry.

2.4.1 EU Renewable and Solar Technology Policy

PV has been selected by the Green Paper adopted by the European Commission on 29 November, 2000 and entitled "Towards a European strategy for the security of energy supply", as one of the elected sources of electric power generation.[147] In the Green Paper, photovoltaic solar cells are recognized as beneficial to small-scale power generation, and subject to geographical differentiated availability according to three insulation zones corresponding to the Mediterranean (high-insulation zone), mid-latitude (medium-insulation zone) and north European countries (low-insulation zone). In 2006, the European Commission reiterated that PV is mainly a decentralized technology.[148] It specified that PV sector has a high technology component and that thanks to its modular nature it was very well suitable for installation on roofs of buildings. This preference towards using PV in small-scale generation systems was supported, in the view of the European Commission, by technical advantages in the energy transmission and distribution of power produced on-site.

Furthermore, the creation of *European Technology Platforms* in 2001 has been a very useful instrument to gather researchers, industries and other stakeholders within the European Union to define common research agendas and deployment strategies. In this framework, the *Photovoltaic Technology Platform* was an initiative intended for three different objectives. First, it was meant to mobilise all the actors involved in PV technology research both from the industry and government research centres sharing a long-tem European vision for PV. Second, it aimed at realizing the *European Strategic Research Agenda for Photovoltaic* for the next decades and giving recommendations for implementation. Third, it was tailored for ensuring that Europe maintained the industrial leadership in the PV power sector.[149]

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[147] COM(2000) 769 final

[148] COM(2006) 849 final

[149] http://www.eupvplatform.org/fileadmin/Documents/Statements/100216_PVTP_statement_on_module_technologies.pdf

In 2007 the European Union proposed a *European Strategic Energy Technology Plan entitled "Towards a low carbon future"* (hereinafter referred to as Set-Plan). [150] This act underlined the pivotal importance of the investment in research and development into the renewable energy sector with the aim of lowering the cost of clean energy and therefore put the EU industry at the forefront of the low carbon technology sector. This act advocated the adoption of dedicated policy towards the development and deployment of cost-effective low carbon technologies. Also, the act made an interesting comparison with other industrial innovators, such as Japan and the US, warning against the risk of falling behind in the technology race if the European Union does not adopt a new and comprehensive energy technology policy.

From an industrial standpoint, the Set-Plan aimed at joining the forces of six *European Industrial Initiatives* (Solar, Wind, Bio-energy, Carbon Capture and Storage, EU electricity grid and nuclear fission). The "*Solar Europe Initiative"* was aimed at furthering research and technology innovation in the solar energy field, with the aim of reaching 15% of the final electricity demand by 2020, of which 12% from PV technology, and 3% from CSP. Although this initiative was industry led, it called for cooperation between European industry and the research community to make collective investments needed to accelerate technology progress in the solar field.

2.4.2 EU Renewable and Solar Energy Policy

In 1997 the European Commission issued a Communication known as the White Paper on "Energy for the Future: Renewable Sources of Energy"[151]. This Communication set out the Community Strategy and Action Plan to double the share of renewable energy from 6 to 12% in gross inland production by 2010. As for PV, the White Paper encouraged PV systems to be integrated in building construction and in public spaces, and it proposed the introduction of the net metering PV system, where PV electricity sales to utilities from private customers should be priced so as to allow direct reversible metering. Moreover, PV was recognized as a high technology with strong export potential in a very competitive global market.

In this framework the PV industry in Europe, especially the many small and medium enterprises active in the field, should be supported in the effort to bring domestic and export markets off the ground. Even though PV technology has reached a certain maturity, there are many obstacles to its market penetration. In order to assist a real take off and make progress towards the objective of doubling the EU renewable energy sources share by 2010, the European Commission proposed a campaign for take off of 1,000,000 photovoltaic systems, half in EU and half in third countries, that would mean new capacity of 0.5 GW in the Union and 0.5 GW in third countries.

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[150] Communication from the Commission: COM (2007) 723 final

[151] White Paper (1997), COM(97) 599 final

Nevertheless, one of the most important legislative action undertaken by the EU in the field of renewable energy policy was the Directive on the promotion of electricity produced from renewable energy sources in the internal electricity market[152]. Directive 2001/77/EC was issued on 27 September 2001 by the European Parliament and the Council, and required Member States to set national indicative targets consistent with the European Union's global indicative target of 12% of gross national energy consumption for the EU-15 by 2010[153]. Electricity would represent 22,1% of this percentage, as the indicative share of electricity produced from renewable energy sources in total European Union's electricity consumption by 2010.[154] With the 2004 enlargement, the European Union's overall objective became 21% for the EU-25 by 2010.[155]

The renewable electricity Directive concerned electricity produced from non-fossil renewable energy sources, thus including power generated by PV. Nonetheless, there are not specific targets concerning electricity from PV sources. In conclusion, the Directive has represented a historical step in the development of renewable electricity, and of solar PV as well, and it has been a main driving force behind new policies being implemented. In a global context, the European Union plays an important role with regard to the use of renewable energy sources thanks to its favourable legislation and a successful mandate system for targeting share of electricity generation from renewable energy sources in the EU final total energy consumption.

Directive 2001/77/EC has been replaced by the Directive 2009/28/EC[156] of the European Parliament and the Council on the promotion of the use of energy from renewable sources. This new Directive was adopted on 23 April 2009 and it entered into force in June 2009. Although it is out of our analysis on the effects that the policies have played on the national's company performance, it will play an important role in influencing the German national policies. Therefore, I will briefly mention it and its possible effects on the German PV market.

Directive 2009/28/EC set new binding targets in the EU context, in particular it set that 20% of the European Union's total final energy consumption is to be met from renewable energy sources by the year 2020. These new targets have to be met through the adoption of binding national targets for the share of energy consumption from renewables, and implemented within the context of national renewable energy action plans.[157] The national targets are mandatory and are set based on the respective starting figures for 2005 and the respective available national potential.

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[152] Directive 2001/77/EC, OJ L 283, 27.10.2001: 33–40

[153] White Paper (1997), *op. cit.*

[154] The European Union is considered here as the EU-25, following to the 2004 enlargement.

[155] See the two amending acts OJ L 236, 23.9.2003 and OJ L 363, 20.12.2006.

[156] Directive 2009/28/EC in OJ L 140, 5.6.2009: 16-62.

[157] Member States shall notify their national renewable energy action plans to the Commission by 30 June 2010 specifying how the targets are to be distributed among the relevant sectors.

For Germany a national target of 18% has been set as share of energy from renewable energy sources in gross final consumption of energy by 2020, a good increase compared to the startiong figure for 2005, that was 5,8%. With respect to these national targets, the Directive is based primarily on independent national promotion mechanisms, meaning that Germany as all other EU Member States have the choice of formulating their own promotion system in order to maximize achievement of their PV potential.

In conclusion, the European Union directive would allow the creation of a comprehensive, reliable and stable legal framework and therefore would lay the foundation for the continued successful expansion of PV electricity market in Europe and in Germany.

2.5 Solar Energy and Technology Policies in Germany

Among European countries, the one that showed on average the best results of the adopted technology and energy policies on the amount of PV power generated is no doubt Germany. Therefore, we will take Germany as our case study in Europe.

In the course of the next sections we intend to demonstrate the important role that the considerable amount of public and private investments in PV RD&D combined with a favourable national legislation and optimal promotion policies have played in the development of the flourishing German PV industry.

The German growth of energy produced by photovoltaic sources is also part of a Europe-wide strategy: pursuant to the national indicative targets laid down in the EU Directives 2001/77/EC, Germany implemented dramatically its renewable energy production and in 2009 it reached 16.4%, thus surpassing the target of 12.5% of its gross final electricity consumption from renewables by 2010. As for the share of PV power over final electricity consumption this also increased radically from the year of the 2001 Directive adoption to 2009, from 0.01% to 1.1% respectively.

The following two sections will analyze first the German technology policy with public and private investments in solar energy technology RD&D (Sec. 2.5.1); and second, the German energy policy made up of incentive measures and promotion policies that have contributed to the growth of the German photovoltaic industry (Sec. 2.5.2).

2.5.1 German Solar Technology Policy

Ever since the first Oil Crisis in the 1970s, the German Federal Government has supported research and development in the fields of renewable energies, even though since the late 1990s research expenditure on renewable energy technologies has noticeably increased. Germany, together with the United States and Japan, accounted for 70.4% of IEA government renewable energy RD&D funding in the 1974 – 2002 period.[158]

If we consider solar energy, the German share of PV technology on total energy RD&D expenditure in the period 1990 – 2002 was 12.5%, whereas the share of PV technology on renewable energy RD&D funding in the same period of time was 48.4%.[159] That means that German national expenditure allocated to RD&D in the PV technology was almost half of the

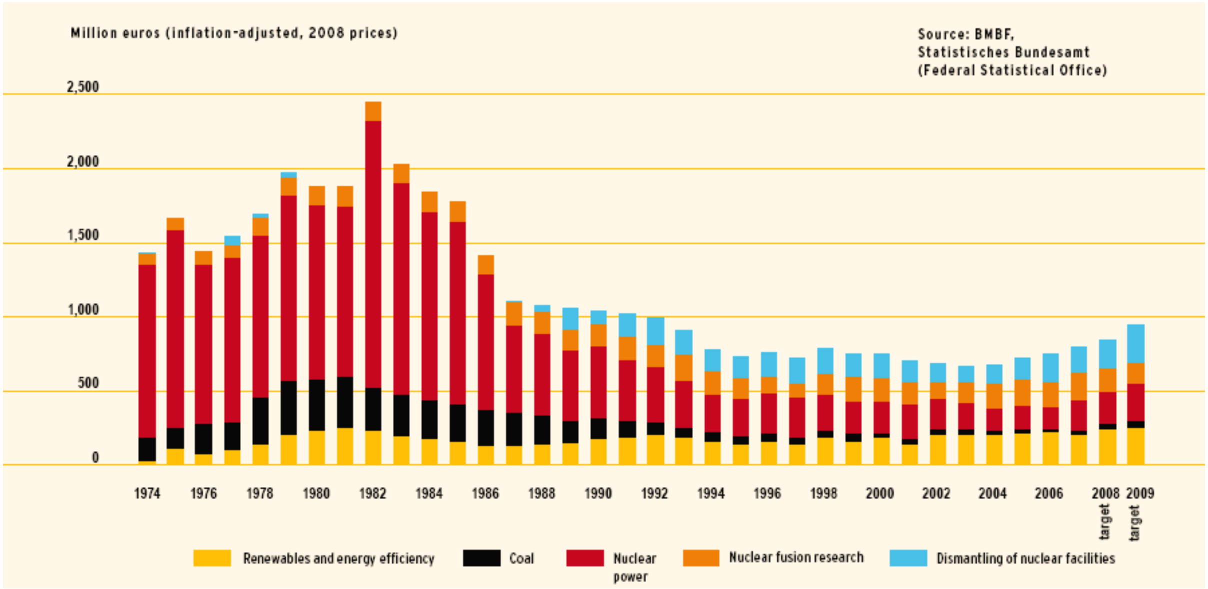
[158] OECD/IEA (2004), Renewable Energy, Market & Policy Trends in IEA Countries: 53

[159] The share of PV technology on renewable energy RD&D funding over the period 1990 – 2002 in Japan was 59.6 % compared to 32.6 % in the US %.

budget devoted to renewable energies all considered from 1990 to 2002.[160] The average renewable budget allocated by Germany to PV in 1990 - 2002 was $40 million.

In sum, in the 1970s and the 1980s public investments in energy RD&D were focused on nuclear energy and on technology innovation in the fossil fuels' field. In the 1990s this focus shifted towards RD&D in renewable energies' technology, thanks to the diversion of public funding from nuclear to renewables due to the successful commercialization of the first and second nuclear generation. From the late 1990s the focus on renewable energy increased considerably and the public spending in renewable energy RD&D reached a very high level and allowed many innovation in the field of PV power technology in Germany (Fig. 2.7).

Figure 2.7 German federal funding on energy science, research, and development.



Source: BMU (2008a)

The German Ministry for the Environment, Nature Conservation and Nuclear Safety (hereinafter BMU), has been responsible for funding research projects on renewable energies and PV power since 2002. As part of the *"High-Tech Strategy"* for Germany, a technology program that was launched in August 2006, the BMU's budget for research and development in the field of renewable energies was scheduled to increase by around $7 million per annum as of 2007. By this program the German Government supports not only basic research through institutional funding. It also funded R&D projects that target priority topics arising from strategy discussions with science and industry. In particular in the field of PV technology the High-Tech Strategy aimed at: lowering the cost of silicon-wafer technology; and progressively developing thin-layer technology to help this technology achieve a

[160] OECD/IEA (2004), *op. cit,*: 56

breakthrough on the market. In 2007, the BMU approved new research projects in the field of renewable energy technologies totalling $140 million.[161]

In 2008, additional funds to promote research in the field of renewable energy sources, amounting to $15 million, have also been made available to the BMU from the "*Climate Protection Initiative"*.[162] In the framework of this initiative, in 2008, the BMU approved 169 new research projects on renewable energies with a volume of $220 million. The Climate Protection Initiative's goal was to advance innovative model projects, by promoting climate protection measures for increased energy efficiency and greater use of renewable energies.[163]

Although in the four years from 2005 to 2008 funding to PV projects as a share of total funding to renewable energies all considered was high and reached 44% (Fig. 2.8), it decreased from the period 1996 - 2005 when the share was as high as 54.4%.[164] The 2008 funding to solar photovoltaics decrease was due to both PV technology maturity and diversion of funding towards new directions in solar energy technology, i.e. the concentrated solar power. The BMU approved 38 new photovoltaic projects (compared with 49 in 2007), corresponding to a funding volume of $60 million (2007: $57 million). PV newly approved funding in 2008 corresponded to a proportion of 26.3% over a total funding allocated to all renewable energy sources (Fig. 2.9). Since 2009, the amount of R&D funding allocated to PV by the BMU further decreased to $44 million, that has been made available for 36 PV R&D projects.[165]

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161 Federal Ministry of Education and Research (BMBF) (2006). "The High-Tech Strategy for Germany".

162 BMU, The Climate Initiative, http://www.bmu-klimaschutzinitiative.de/en/home_i

163 The Climate Protection Initiative consists of national measures (€280 million) and international measures (€120 million).

164 In the Framework of the 4th Energy Research Program Germany invested 292.3 million euros in PV research funding in the period 1996 – 2005.

165 Germany Trade and Invest (2010), "The Photovoltaic Industry in Germany".

Figure 2.8 Average breakdown of German funding to renewable energies (2005 – 2008).

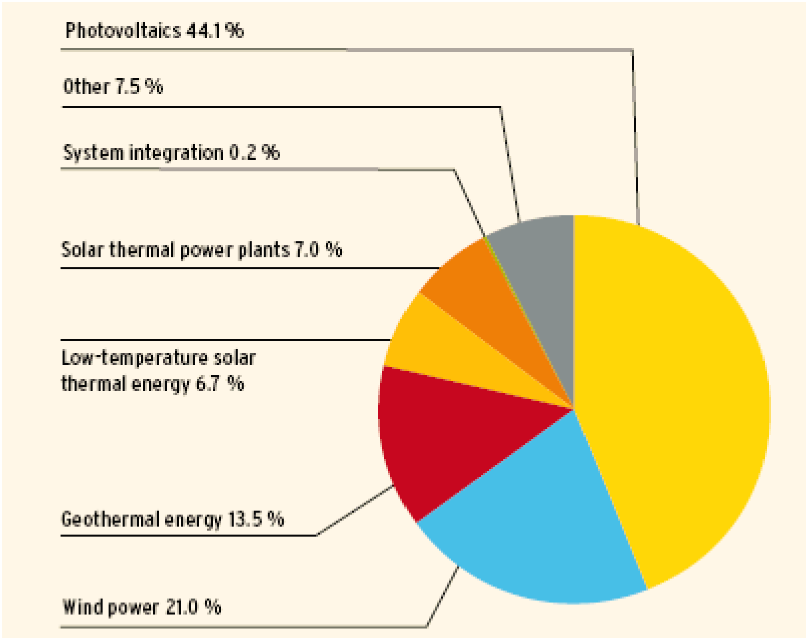
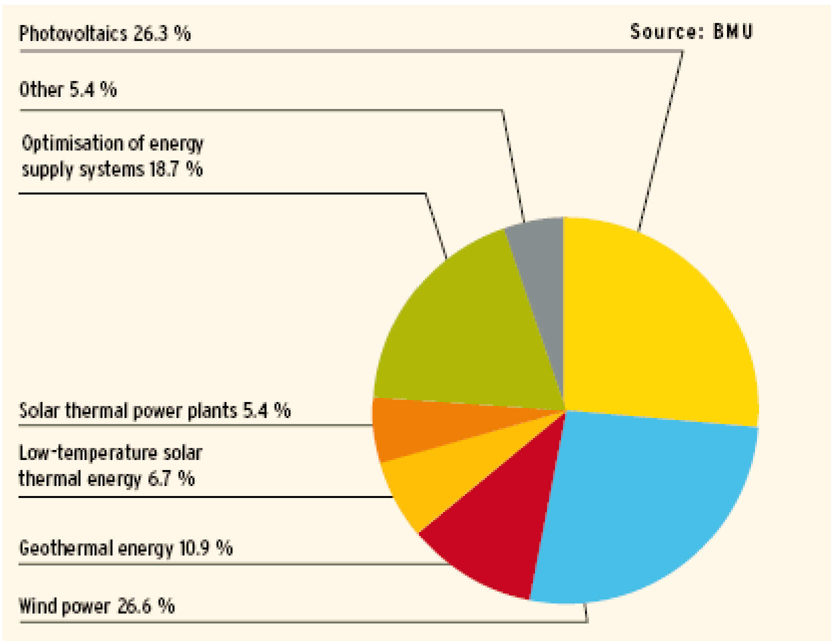


Figure 2.9 Proportion of approved funding to renewable energies (2008).

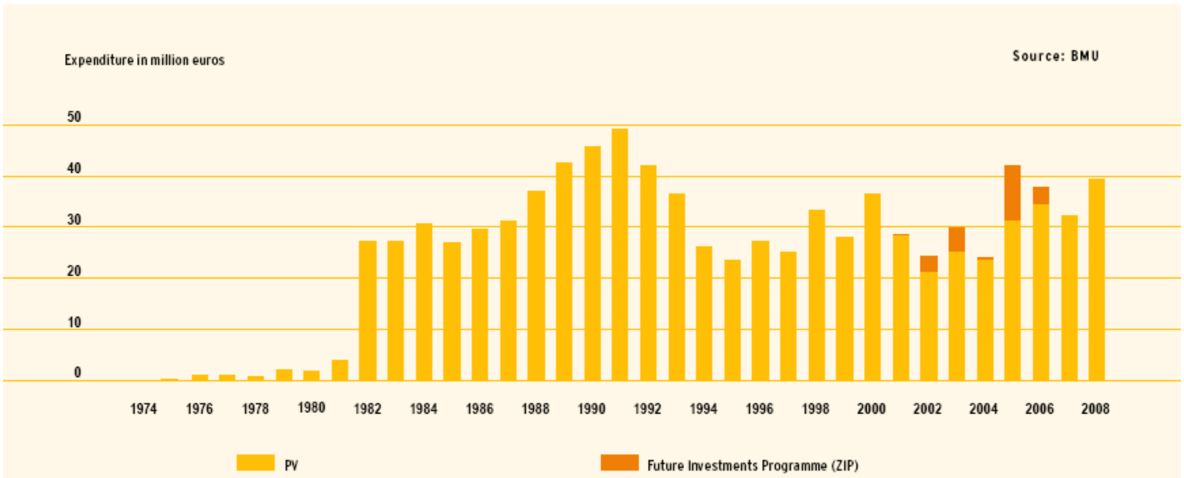


Source 2.8 and 2.9: BMU (2008a)

This pragmatic approach to RD&D by the Federal Government resulted in the numerous prizes that have been awarded to many funded projects. Just to make a few examples: the Eni Award 2008, in the Science and Technology category, was awarded to researchers at Fraunhofer Institute for Solar Energy Systems (hereinafter Fraunhofer-ISE) for recognition of their work on super-efficient thin silicon solar cells; the Innovationspreis der Deutschen Wirtschaft (the Germany Industry Innovation Prize) was awarded to Concentrix Solar GmbH in January 2008 in the Start-ups category for recognition of it successful implementation of innovative PV concentrator technology, which achieves efficiency levels almost twice those of conventional photovoltaics.[166]

Figure 2.10 describes the German annual project funding in the PV field. It can be noted that since the early-1980s the budget allocated to R&D projects in the field of PV has been growing steadily, it increased further at the end of the 1980s, and reached its peak in 1991 when the expenditure amount reached almost half a billion euros. The reference to "*Future Investments Program"* is not relevant for photovoltaics, but instead it involves other renewable energy sources such as solar thermal projects.[167]

Figure 2.10 Annual project funding in the PV field and other solar projects (1974 - 2008).



Source: BMU (2008a)

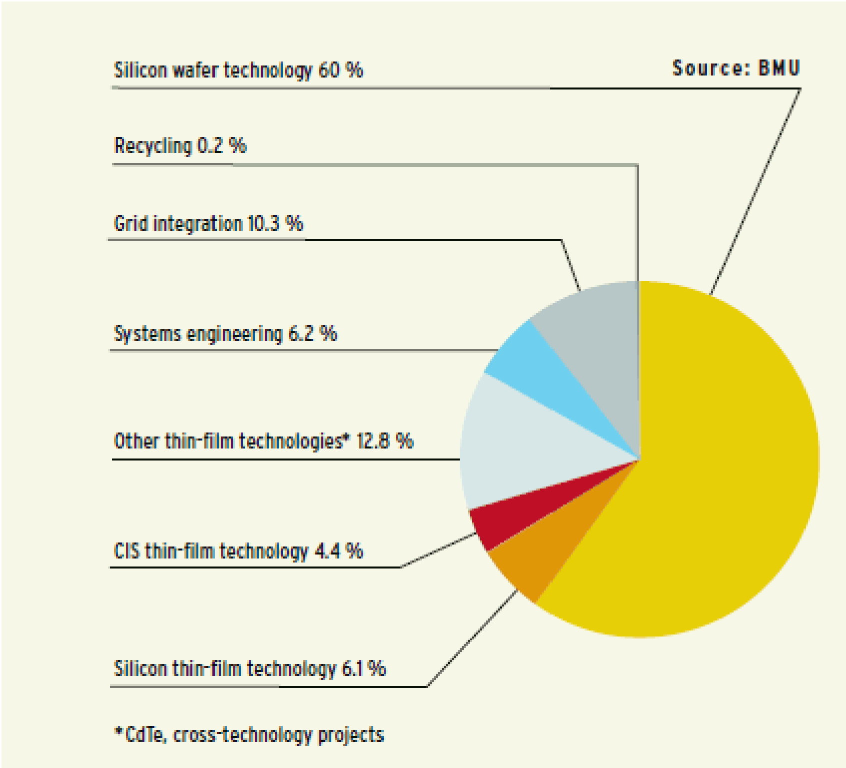
[166] See also as far as CSP is concerned the Energy Globe Award to German owned company Solar Millennium AG for the development of Europe's first parabolic trough power plant, the Andasol plant in Spain.

[167] ZIP was born in May 2001 when the Budget Committee of Germany's Federal Parliament allocated approximately 30 million euros to the BMU to finance R&D in the field of green energies including: solar thermal power generation, geothermal power generation, offshore wind farms, stationary fuel cells, and biomass.

Interestingly, Germany especially focused its RD&D activity on new PV technology areas such as organic photovoltaics, and in 2007, the German Ministry of Education and Research committed to invest $494 million to support groundbreaking research on organic PV.[168]

Figure 2.11 describes the distribution of different PV technologies among approved research funding in 2008. It can be noted that silicon-based wafer technology is still the relevant funded technology with 60% of the total PV funding. Research funding in thin-film solar cells occupies still a small share of the total R&D spending in solar technologies: the other thin-film technologies, among which are Cadmium Telluride solar cells, reach 12.8%, Silicon thin-film cells reach 6.1%, and Cadmium Indium Selenium thin-film cells reach the smallest share of 4.4%.

Figure 2.11 Distribution of different PV technologies in approved research funding (2008).



Source: BMU (2008a)

[168] This agreement was signed with Basf and Bosch.

2.5.1.1 Research and Development Tax Credit System

In Germany, as in the United States, the R&D expenditure is deductible if it is in the nature of revenue expenditure and it is subject to amortization if it is in the nature of capital expenditure. Similarly, as regards the tax treatment under the general (non-incentive) scheme of taxation, the tax laws in Germany as in the United States do not differentiate whether the expenditure was incurred within the country or outside the country.[169]

As for corporate income tax legislation, Section 51(1) No. 2 of the Income Tax Law (hereinafter EStG) of 1934 defines R&D activities as the ones aimed at basic research as well as at the development of new products or new production processes and at "essential" advancement of products or production processes. Apart from this provision, there is no legal provision under German corporate income tax legislation defining R&D expenditure.

As for treatment of R&D expenditure, R&D costs constitute deductible business expenses as it is ruled in Section 4(4) of the EStG in conjunction with Section 8(1) of the Corporate Income Tax Law (KStG). For purposes of tax accounting law certain R&D costs fall within the scope of intangible assets, and may only be considered as assets, and depreciated thus reducing taxable profits, if they have been acquired in return for payment. Therefore, the expenditure for a taxpayer's own R&D activities carried out in the field of *basic research* may *not* be capitalized as *an asset*, and consequently may not be depreciated. As for applied research, the expenditure for a taxpayer's own activities carried out for purposes of *new product development* must be capitalized as *an asset* if it entails the commencement of the production of a certain product and it must be depreciated. On the other hand, the *advancement of products* to the extent that essential changes of these products are developed may *not* be capitalized as *an asset,* and may not be depreciated.

It is worth noting that unlike the US corporate tax legislation there are no specific incentives under the German corporate income tax legislation. Moreover, similarly to the United States there are no R&D incentives under the German wage tax legislation.

2.5.1.2 Patent Law and Policy

Improving the protection and utilization of intellectual property in the PV power field constitutes a priority for the German government. Under the German Patent Law or *Patentgesetz,*[170] inventions from all fields of technology are patentable. Under section 1 of the German Patent Law there are three criteria for patentability, which are common to other European as well as US patent laws. The first one is *novelty*, meaning that an invention is new

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[169] IBFD, *op. cit.,* December 2004

[170] Text of December 16, 1980 as last amended by the Laws of July 16 and August 6 1998.

if it does not form part of the state of the art. The state of the art comprises all knowledge made available to the public by any means anywhere in the world, before the date of filing. The second one is the *inventive step*, which means that the innovation must sufficiently differ from known prior art. The third one is *industrial applicability*, which means that an invention is deemed to be industrially applicable, that is it can be produced or used in some area of industry. We will see that these same criteria are not interpreted in the same way in Asian countries, and specifically in Japan (Sec. 2.6.1.2), which may explain an imbalance in patent numbers.

The most prolific entities in Germany based on the number of PV patents are the Fraunhofer Institute and Q-Cells, the German leading PV company. Despite the fact that Germany has the largest amount of installed PV power, as of January 2010 the Fraunhofer Institute held the fifth-largest number of PV patents in the world, while Q-Cells held 19 PV patent families[171]. What may be surprising is that, the top 5 PV patent applicants to the European Patent Office in 2009 were Asian companies, and specifically Japanese.[172] It appears that Japanese companies have rushed to extend their patent protection in Europe to counteract the young European competition. This might be the reason for German as well as other European companies not to patent new inventions, but rather to protect them as trade secrets for as long as possible. After all, international patent protection is still difficult and expensive to enforce, especially in Asian countries.

[171] A patent family is the same invention disclosed by a common inventor and patented in more than one country. R. Harrison, "Photovoltaic Solar Cells: Patents in Europe", 6 January 2010, http://www.tangible-ip.com/2010/photovoltaic-solar-cells-patents-in-europe.htm

[172] http://documents.epo.org/projects/babylon/eponet.nsf/0/CD79D480D223A73AC125770D004F50E6/$File/leading_applicants_2009_photovoltaics.pdf

2.5.2 German Solar Energy Policy

The promotion of electricity produced from renewable energy sources including solar PV in Germany started in 1991 with the adoption of the *Electricity Feed Act* (Stromeinspeisungsgesetz, hereinafter StrEG). In 2000 the StrEG was replaced by the *Renewable Energy Sources Act* (Erneuerbare-Energien-Gesetz, hereinafter EEG). Both acts were based on the principle of tariffs for renewable generated electricity to be paid by grid operators. Since the introduction of Germany's feed-in law in 1991 these tariffs were technology-specific tools, therefore they had been differentiated depending on the renewable technologies used, with a more and more refined differentiation over time to take account of technological developments. Nevertheless, in the StrEG the same feed-in tariff was allocated to PV and wind, whereas in the EEG these tariffs were differentiated in favour of PV.[173]

Thanks to the EEG, and especially to its two amended versions of 2004 and 2009, a vibrant marketplace for technologies to generate electricity from renewable energy sources and PV has developed in Germany.[174] The share of renewables in gross electricity consumption has doubled, from around 3% in 1991 to 6.3% in 2000 (entry into force of the EEG), and it more than doubled to over 15% in 2008. Although in 2008 solar photovoltaic accounted for only 0.7% of Germany's gross electricity consumption, solar electricity is guaranteed by far the largest financial support among all renewable energy technologies, appropriating 24.6% of the overall feed-in tariffs in 2008.

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[173] According to Jacobsson and Bergek the StrEG had an important drawback, that is it was not persistent enough to allow for long life times of the equipment and a long learning period because it was linked to the market price, in contrast to the EEG that was made persistent because it guaranteed a price for 20 years. In their opinion, the remuneration was too low to stimulate a demand for technologies with a higher cost level than wind turbines, i.e. solar cells. S. Jacobsson & A. Bergek (2004), "Tranforming the energy sector: the evolution of technological systems in renewable energy technology", *Industrial and Corporate Change,* Vol. 13, No. 5*:* 815-849.

[174] Many other incentive programs exist, of which the most remarkable is the KFW Renewable Energy Program. Through its "Environmental Protection Loan Program" the German Development Bank (KfW) offers attractive 20-year loans at below market interest rates to sup- port renewable energy installations - with particular focus on SMEs and private households. These mainly invest in small-sized rooftop PV systems.

2.5.2.1 The PV Roofs Programs

The German government gave a clear boost to its solar energy future through two market-pull policy programs specifically addressed to PV technology: The first was the "*1,000 Roofs Program*[175]" which started in 1991 1993, and the second was the "*100,000 Roofs Program*[176]" launched on 1 January 1999 and ended in 2003.

With the first program Germany became the first country worldwide to launch a major solar installation initiative. Lessons learned from this program were applied in Japan in 1994 and in California in 2006. The "*1,000 Roofs Program"* provided *rebates* for up to 60% of system costs, and had installed roughly 2,250 systems totalling 5.25 MW by the time of the program's sunset.[177]

The second program aimed at stimulating the installation of 100,000 grid-connected PV systems totalling 300 MW by 2004. In order to reach this goal, the program granted *loans* at a "reduced" interest rate of 0% for PV systems for the first two years and a waiver of the last instalment of up to 12.5% of the investment. The early success of this program, in part due to the introduction of the EEG in April 2000, has prompted the German government to advance the 300 MW target date by one year to 2003 and to outdate the 300 MW cap.

According to the German Solar Industry Association, this market policy was aimed at developing a strong PV national industry by stimulating the demand side, thereby creating new jobs and increasing the competitiveness of the German companies on the world market.[178] In combination with the "100,000 Roofs Program", the provisions of the EEG led to compensation payments, which for the first time made electricity generation from "solar radiation energy" an attractive option for private investors. The program ended successfully in 2003 and in order to fill the gap created by its termination, the government decided to increase the feed-in tariff provided by the EEG, by amending it and passing a new version of the EEG in 2004 (described below). In total from 1999 to 2003, 45,858 PV systems with 345.5 MW were subsidized under the "100,000 Roofs Program" with loans of $1.95 billion.[179]

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[175] "1000-Dächer-Programm". The strategy of this program was the stimulus to PV installations through investment subsidies plus feed-in tariffs.

[176] "100,000-Dächer-Programm".

[177] I. Weissand, P. Sprau (2002), "100,000 Roofs and 99 Pfennig: Germany's PV Financing Schemes and the Market.", *Renewable Energy World*.

[178] G. Stryi-Hipp (2004), "The effects of the German Renewable Energy Sources Act (EEG) on market, technical and industrial development", German Solar Industry Association, 19th European Photovoltaic Solar Energy Conference, Paris: 1

[179] Calculated at 2003 average annual exchange rate. Gerhard, *op. cit.*: 3.

2.5.2.2 Feed-in Tariffs

The *Renewable Energy Sources Act*[180] entered into force on 1 April 2000 replacing the *Electricity Feed Act*[181]. The EEG was passed in the lower House of the German Parliament (Bundestag) on February 25, 2000, whereas the upper House of Parliament (Bundesrat) passed the act later on March 17, 2000.[182]

It is interesting to note that the provisions of the EEG are based on Directive 96/92/EC[183] of December 1996 concerning common rules for the internal market in electricity, and they are designed to implement article 20a of the German Constitution[184], which stipulates that natural resources must be protected as a responsibility vis-à-vis future generations.

By regulating the purchasing and compensation of energy which has been produced exclusively from renewable sources, the EEG has the purpose to facilitate a sustainable development of energy supply in order at least to double the share of renewable energy sources in total energy consumption by the year 2010.[185] In order to attain this objective *new* renewable energy sources become fundamental, and as far as the scope of this study is concerned, the act includes specifically “solar radiation energy”.[186]

The only limit is that the EEG shall not apply to electricity produced by installations for the generation of electricity from “solar radiation energy”, with an installed capacity of over 5 MW. This limit is even stricter amounting to 100 KW in the case of solar installations which are not attached to or built on structures which are primarily used for purposes other than the

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[180] Federal Law Gazette (Bundesgesetzblatt) 2000 I: 305.

[181] This Act, which entered into force on 1 January 1991, mainly provided an impetus for the wind energy sector, but the compensation rates have not been sufficient to stimulate a large-scale market introduction of electricity generated from other sources, especially photovoltaic cells. Within Parliament, politicians from CDU, SPD and the Greens, organized within the Eurosolar Parliament Group, a German environmental organization, worked for the acceptance of the law, which was passed in 1991 with support from the majority of the CDU members (which then formed the Government).

[182] The states ruled by the SPD or the Red-Green coalition voted for the law. The city-states Berlin, Bremen, and Hamburg, governed by a coalition of SPD and CDU, and Thuringia, governed by the CDU, agreed. States governed by the CDU/CSU and the FDP voted against the law. The Rhineland Palatinate abstained.

[183] OJ L 27, 30.1.1997: 20–29

[184] Basic Law for the Federal Republic of Germany (Grundgesets) Article 20a [Protection of the natural bases of life]: Mindful also of its responsibility toward future generations, the state shall protect the natural bases of life by legislation and, in accordance with law and justice, by executive and judicial action, all within the framework of the constitutional order.

[185] See § 1 of the EEG. This objective is related to the commitment on the part of the Federal Republic of Germany to reduce greenhouse gas emissions by 21 percent by the year 2010 in the framework of the European Union’s burden sharing as laid down in the Kyoto Protocol, and it is also linked to the German Government to reduce carbon dioxide emissions by 25 per cent by the year 2005, relative to 1990.

[186] The term “solar energy”, which was used in the *Electricity Feed Act* has been replaced by “solar radiation energy”, including both photovoltaic installations and installations for solar thermal electricity generation.

generation of electricity from "solar radiation energy".[187] The purpose of this limitation is to prevent a continuation of the sealing of open space for electricity generation. In fact, the building structure which are covered by the rules on compensation include roofs, façades, and noise protection walls, therefore preferring decentralised smaller installations to large-scale installations.

The EEG compensation scheme is based on a systematic approach introduced in the *StrEG* and guided by the European Commission through the recommendations contained in its 1997 White Paper "Energy for the Future: Renewable Sources of Energy".[188] The most important aspect is that, as far as "solar radiation energy" is concerned, the EEG increased the feed-in tariff to 0.51 euro per KWh from 0.68 euro per KWh (Tab. 2.3), and this shall be payable for *newly* commissioned installations for a period of 20 years after the year of commissioning, whereas for *existing* installations the year 2000 shall be considered to be the year of commissioning.[189]

Table 2.3 Minimum PV feed-in tariffs €/KWh according to StrEG and EEG 2000.

Years	***€/KWh***
1991 - 1999	0.068
2000	0.506
2001	0.506
2002 (-5%)*	0.481
2003 (-5%)*	0.457

* Reduction of the minimum compensation paid by 5% annually.

Source: Elaboration from StrEG and EEG 2000 data

The compensation regime had two main characteristics. First, the EEG foresees the reduction of the minimum compensation paid by 5% annually for *new* electricity installations commissioned as of 1 January 2002 (Tab. 2.3). Second, there is no obligation of compensation for PV installations commissioned after 31 December of the year following the year in which these installations reach a total installed capacity of 350 MW.[190] This number would have accounted for the 50 MW of existing capacity in place at the time the act was written, as well as the 300 MW goal of the 100,000 Roofs Program.

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[187] See § 2 of the EEG.

[188] COM(97) 599 final (26/11 97).

[189] With the exception of wind energy, existing and newly built installations are treated alike by this act. Wind energy has already benefited from compensation payments under the former Electricity Feed Act.

[190] § 8 of the Act.

If the degression rates specified in the EEG have been determined by means of scientific studies, subject to the provision that the rates identified should make an installation to be operated cost-effectively, based on the use of state-of-the-art technology, however, there is no guarantee that the cost of a given installation will be covered.

In early 2003, before the "100,000 Roofs Program" ended, heavy political discussion about the future support for renewables and the amendment of the EEG took place. The feeling of insecurity about the future support for renewables resulted in a very fast increase in the number of applications to the "100,000 Roofs Program" till the termination of the program. After the end of the program, the PV sector expected a dramatic slump in the PV market. To avoid this critical situation, in November 2003 the Parliament passed the amendment of the PV part of the EEG and adopted the "PV-Vorschaltgesetz" (preliminary act), which regulates the new PV feed-in tariffs starting as of 1 January 2004.[191]

The formal *Act revising the legislation on renewable energy sources in the electricity generation sector*[192] was adopted in July 2004 and entered into force on 1 August 2004.[193] Alike the EEG 2000 where the renewable energy target was to double the share of renewable energy sources in total energy consumption by 2010, this new act at its article 1, paragraph 2, made as its primary purpose the contribution to the increase in the percentage of all renewable energy sources in power supply to at least 12.5% by 2010 and to at least 20% by 2020.

The most relevant difference from EEG 2000 was the abolishment of the cap of 100 KW per system. Therefore, megawatt-sized plants were then eligible, which permitted raising more PV funds. The absence of a cap in solar electricity generation represented certainly the most important characteristic among the amendments to the EEG 2000, and thus for the effectiveness of the whole feed-in tariff system.

The other substantial difference of EEG 2004 with respect to EEG 2000 concerns the introduction of a different feed-in depending on the size of the systems and to whether they were installed on top of the building, in the façade of a building or as a free-range systems. If the plant is installed on top of a building the fees shall be calculated according to tab. 2.4. If instead the PV system is installed in the façade, an additional grant is given in order to stimulate the building-integrated PV market. The PV free-range systems remained at the same tariff as before (0.457 €/kWh) although reduced by 5% annually from 2002 onwards.

[191] Federal Law Gazette (Bundesgesetzblatt) 2003 I: 3074.

[192] Federal Law Gazette (Bundesgesetzblatt) 2004 I No. 40, Bonn, 31 July 2004.

[193] Act implementing Directive 2001/77/EC of the European Parliament and of the Council of 27 September 2001 on the promotion of electricity produced from renewable energy sources in the internal electricity market (OJ L 283 p. 33), as last amended by the Acts of Accession of 16 April 2003 (OJ L 236 p. 586).

Table 2.4 Minimum PV feed-in tariffs €/KWh for rooftop systems according to EEG 2004.

Capacity	***€/KWh***[194]
≤ 30 KW	0.574
≥ 30 KW	0.546
≥100 KW	0.540

Source: Elaboration from the EEG 2004

In the EEG 2004 it was decided that as of 1 January 2005, the minimum fees paid for new plants commissioned after that date shall be reduced by 5% annually, and starting as of 1 January 2006, the reduction will be increased from 5% to 6.5%. As in the EEG 2000, the minimum feed shall be paid from the date of commissioning for a period of 20 years including the year of commissioning.

In October 2008 the Renewable Energy Sources Act was newly amended by the German Bundestag with the adoption of the new *Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector and Amending Related Provisions.* This act entered into force on 1 January 2009 and hereinafter it will be referred to as the EEG 2009.[195] The annual digression rate increased as of 2009, thus reducing the tariffs in the year 2010 up to 8% annually for smaller rooftop systems (≤100 KW), and up to 10% for bigger rooftop systems (≥1,000 KW).[196] As a result, the new fees if the plant is attached to or integrated on top of a building, shall be calculated as in table 2.5.

Table 2.5 Minimum feed-in tariffs €/KWh for rooftop systems according to EEG 2009.

Capacity	***€/KWh***
≤ 30 KW	0.430
≥ 30 KW	0.409
≥ 100 KW	0.396
≥ 1,000 KW	0.330

Source: Elaboration from the EEG 2009

[194] The minimum fees shall be increased by 5.0 cents per KWh if the plant is not completely integrated into the roof and it forms a substantial part of the building.

[195] Federal Law Gazette (Bundesgesetzblatt) 2008, I No. 49, Bonn, 30 October 2008.

[196] From the year 2011 onwards the annual digression rate would be reduced to 9% for all the PV category systems.

In the table above it can be noted the new remuneration category for rooftop installations of a capacity up from 1 MW. Moreover, the previous supplemented values bonus of 0.5 €/KWh for building-integrated installations was cancelled, whereas bonus, similar to a premium on energy efficiency, for those who use PV electricity for self-consumption and do not feed it into the grid were introduced, even though they will receive a reduced feed-in tariff compared to the normal rate.[197] The ratio behind this rule is that since the amount of PV electricity that is self-consumed substitutes expensive electricity from the grid, self-consumers will receive a bonus commensurate with the price of electricity. So for instance, if the price for conventional electricity keeps growing this bonus will likewise increase.

Furthermore, a "sliding scale" for digression was introduced according to the growth of the PV market in a specific year, meaning that if the growth of the PV market (new installations) in a year is stronger or weaker than the defined growth "corridor", the digression in the following year will increase or decrease a percentage point respectively. Based on the market growth of 2007 the top border of the growth "corridor" indicated 15% growth annually. As soon as the growth exceeds this value, the sliding scale will correct the digression.[198] This provision is very important because it allowed limiting the monetary effects of the feed-in regime on consumers without the introduction of a cap. The reasoning behind the sliding scale is that the higher the growth rate of PV production the lower are the manufacturing costs (learning curves), which offers scope for a one-off reduction in fees and an increase in the rate of digression.

Moreover, the EEG 2009 increased substantially market transparency through a registration system. In fact, as of 1 January 2009 all installation operators must register with the German Federal Network Agency by declaring the location and capacity of the PV installation before they can gain network access. It has been decided that by 31 October of each year, the Federal Network Agency, in agreement with the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) and the Federal Ministry of Economics and Technology (BMWi), would publish in the Federal Gazette the notified increase in installed capacity and the resulting digression rate applicable in the following year as well as the applicable tariff levels.

In short, under the StrEG of 1991 the remuneration was too low to stimulate a demand for technologies with a higher cost level than that of wind turbines, as it is the case with solar cells. Therefore, the impact of the provisions of the first German feed-in tariff law (StrEG) on the transformation of the energy sector was initially mainly restricted to wind turbines. When the EEG was adopted in 2000, tariffs were revised in order to stimulate demand for more costly PV electricity generation, and also set at a differentiate levels for PV power. In 2009, tariffs were newly revised and fees for PV power dropped off under the new version of the

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[197] Art. 1, Section 33, ph. (2), EEG, 2009. This feed-in tariff for off grid systems is applicable only for systems with a maximum capacity of 30 KW and it amounts to 0.250 €/KWh in 2009 compared to the normal rate of 0.430 €/KWh.

[198] Art. 1, Section 20, ph. 2a, EEG 2009.

EEG, based on learning-curve effects, which have enabled electricity from PV plants to become even more cost-effective.

From figure 2.12 and 2.13 it can be noted the effects of the feed-in tariffs system and fees in the penetration of all renewable energy sources for electricity generation in Germany. If in 2000,[199] the share of electricity from renewable energy sources (as a total of remunerated and non-remunerated electricity under the EEG) on the total final electricity consumption was 10.6%, this share increased up to 18.7% in 2008. This means that besides the growth of 44% of final electricity consumption from 2000 to 2008, electricity from renewable energy sources all considered got to cover almost a fifth of the total German electricity consumption in 2008. Furthermore, it is worth noting that the electricity remunerated under the EEG grew steadily of almost 6-fold since its adoption in 2000 through 2008, whereas the electricity non-remunerated under the EEG decreased considerably in the first year and then remained stable along the all period considered. PV power share grew steadily and in 2008 it reached 0.81% on the total final electricity consumption in Germany (Tab 2.6).

Table 2.6 Structure of electricity volumes remunerated under the EEG (2000 – 2008).

	2000	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*
Remunerated EEG Electricity (GWh)	10,391	18,145	24,970	28,417	38,511	43,966	51,545	67,010	71,978
Annual Growth of Rem. EEG El.	n/a	74.62%	37.61%	13.80%	35.52%	14.16%	17.24%	30.00%	7.41%
Non-Remunerated EEG El. (GWh)	26,288	20,927	20,790	20,237	19,018	19,602	20,695	20,594	20,801
Annual Growth of Non-Rem. EEG El.	n/a	-20%	-1%	-3%	-6%	3%	6%	0%	1%
Total Final El. Consumption (GWh)	244,663	464,289	465,346	478,101	487,627	491,177	485,203	495,041	495,000
PV Power (GWh)	29	76	162	313	556	1,282	2,220	3,074	4,000
Share of PV Power /Final El. Cons.	0.08%	0.01%	0.03%	0.06%	0.11%	0.26%	0.45%	0.63%	0.81%

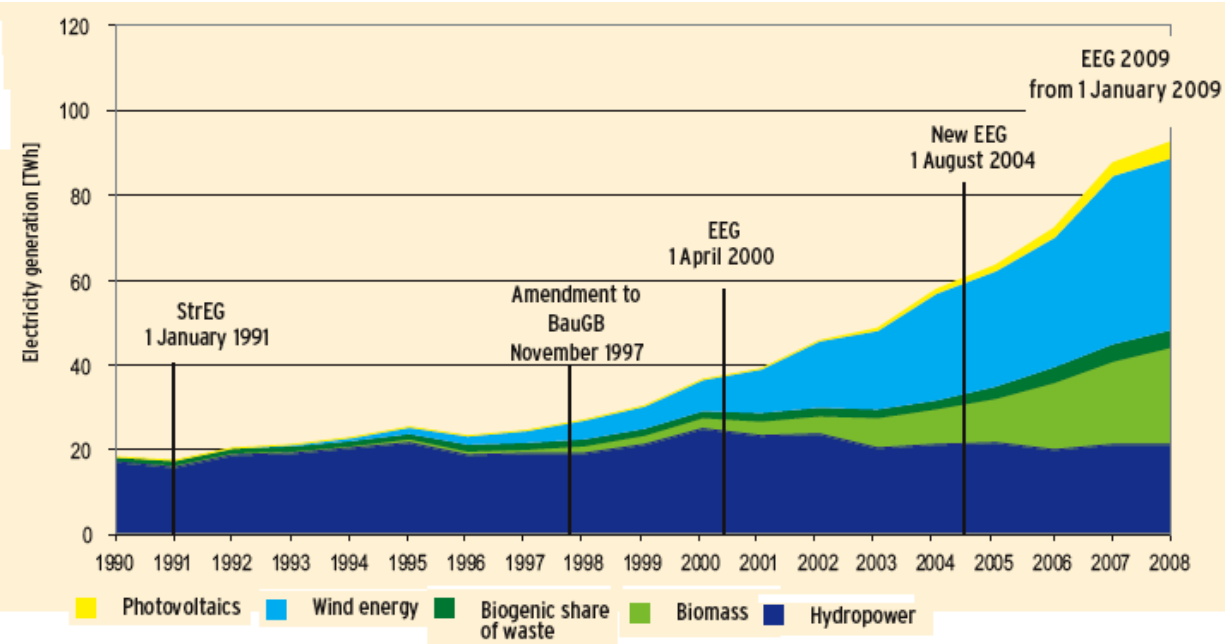
Source: VBN Berlin, BDEW Berlin, ZSW Stuttgart

[199] 2000 data refers to the partial year, from April 1 to December 31, 2000.

In particular, Figure 2.12 describes the development of electricity generation from renewable energies since the beginning of the German feed-in law in 1990 through 2008. It should be noted that among renewable energies photovoltaics only stands at the forth position (4,000 GWh) after wind energy (40,000 GWh), hydropower (5,300 GWh), biomass (19,560 GWh) as for the quantity of electricity generated under the German feed-in tariff in 2008.

The following Figure 2.13 illustrates the feed-in and fees under the StrEG and EEG since 1991 until 2008. It shows that the feed-in of electricity remunerated under the EEG largely contributed to a dramatic growth in the renewable electricity produced since 2000.

Figure 2.12 Development of electricity generation from renewable energies since the beginning of the German Feed-in-Law (1990 – 2008).



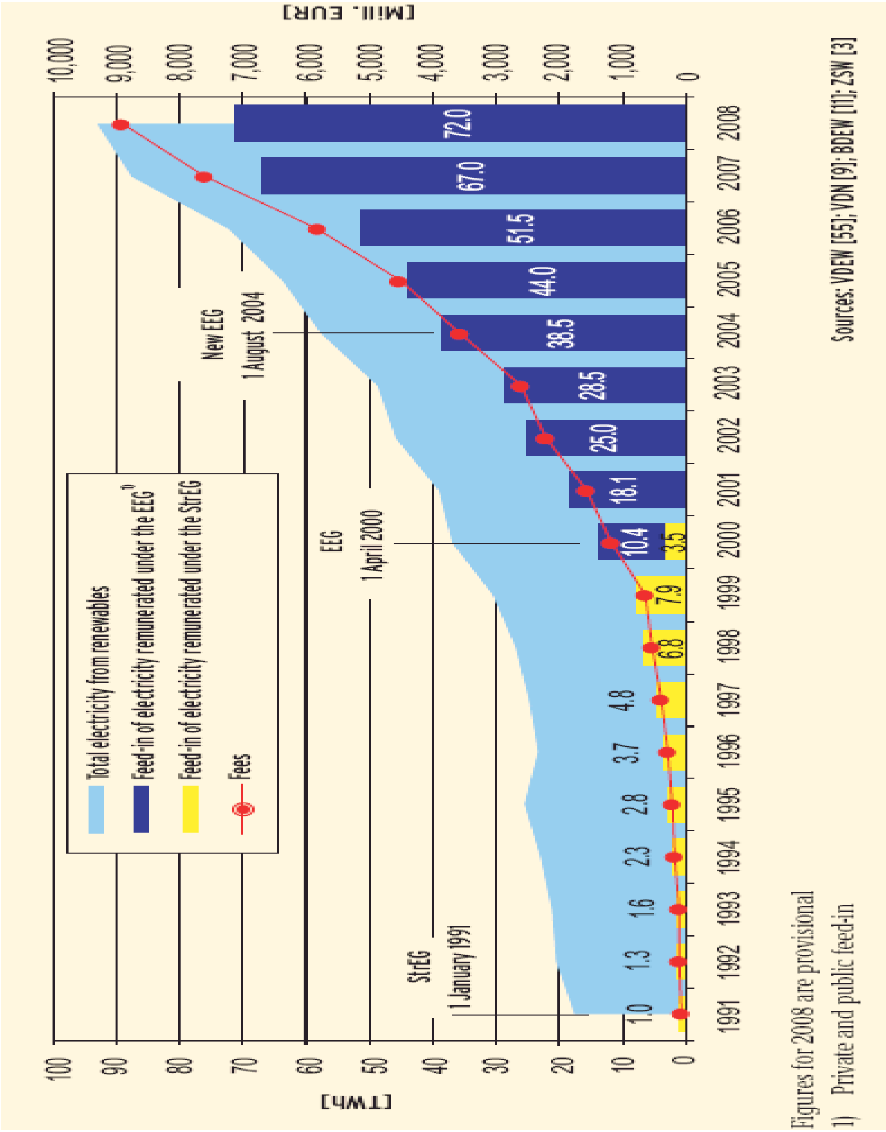
Legend:

StrEG: Act on the Sale of Electricity to the Grid or Electricity Feed Act

BauGB: Construction Code; EEG: Renewable Energy Sources Act

Source: BMU based on AGEE-Stat Working Group on Renewable Energies – Statistics; BMU (2009) "Renewable energy sources in figures – national and international development" (provisional figures)

Figure 2.13 Feed-in and fees under the Act on the sale of electricity to the grid (StrEG) and the Renewable Energy Sources Act (EEG) since 1991.



Source: BMU (June 2009); VDEW, Elektrizitatswirtschaft, vol. 24, 2000; Verband der Netzbetreiber - VDN – e. V.beim VDEW, Berlin; BDEW Bundesverband der Energie- und Wasserwirtschaft e.V., Berlin (www.bdew.de); Zentrum fur Sonnenenergie- und Wasser-stoff-Forschung Baden-Wurttemberg (ZSW), Stuttgart.

2.6 Solar Energy and Technology Policies in Japan

In order to understand Japanese technology policy in the field of renewable energy and specifically on photovoltaic, it is important to examine some aspects that have featured Japanese national RD&D system since the post-war period.

First, Japanese firms were the leaders in the commercialization of new products, despite the fact that the invention was made elsewhere. Especially until the late 1970s, Japanese applied research played a leadership role over basic and precommercial research. The exploitation of foreign basic research innovations involves a considerable level of scientific and engineering expertise. Although research laboratories in many Japanese firms have expanded their shares of RD&D budget, the engineering department of the manufacturing division in the large Japanese enterprises plays a more significant role in the RD&D process.

Therefore, Japanese national science and technology policies gave a substantial contribution to the transformation of the nation's economy, but the success of these policies had been based on the investment decisions of Japanese private companies. On this aspect Mowery and Rosenberg commented: "Japanese firms have been among the most successful commercial innovators in the postwar global economy and have emerged as key source of competitive pressure on US firms in many industries"[200]. This means that the share of national RD&D that is privately financed has been higher in Japan than in the United States, whereas the share of national RD&D public funding in Japan was lower than that in the United States. For example, in 1983 the share of national RD&D public funding in Japan was only 22.2% compared to 46% in the US. Nonetheless, overall RD&D investment has been traditionally high within the Japanese economy and it has exceeded that of the US as a share of GNP since the early 1960s if military RD&D expenditures are removed, or since 1985 if these figures for both countries are included.[201]

Second, the changing place of Japanese innovation within the world economy may lead to significant change in the institutional structure of the Japanese RD&D systems. Japan's contribution to pure science rose in the 1980s and allowed the emergence of the nation at the technological frontier. So, if in the postwar period Japanese science and technology policies supported domestic exploitation of research innovations made elsewehere for commercial innovation, since the 1980s the new objective was towards technology policies that will strengthen the commitment of resources to basic research.

A last feature on Japanese RD&D policy is that universities in Japan received little public research funding, in contrast to the prominent role of universities as performers of basic research within the United States and Germany. As an example, the $4.8 billion that the US

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[200] D. Mowery, N. Rosenberg (1989), *Technology and the pursuit of economic growth*, Cambridge University Press: 219

[201] Japanese RD&D investment share of GNP in 1985 was 2.77%, exceeding the US GNP share of 2.4% in that year.

government provided in support to RD&D in universities is roughly six times what Japanese universities received in public R&D support, and consequently in 1981 US universities awarded six times as many doctoral degree in the sciences and engineering as Japanese institutions.[202] Nevertheless, although university-industry links in Japan were less developed than it was true within the United States and Germany, the Japanese system of higher education made considerable contributions to technological performance of the national economy through the training and production of large numbers of engineers. As we will see this situation is slightly changing today and especially in the renewable and solar energy field many university-industry cooperation agreements have been signed. Despite the limited research linkage, national public laboratories[203] with permanent research staff have been established in the framework of 1985 "Japan Key Technologies Program", and they became potential sources of basic research and efforts had been made to strengthen their ties with the industry through transfer of research personnel.[204]

The *Ministry of Economy, Trade, and Industry* (hereinafter METI) was reorganized and enlarged in 2001 from the former *Ministry of International Trade and Industry*.[205] METI is responsible for energy and power issues and it has centralized the role of RD&D policy maker for energy technology policies. It is worth noting that the Japanese Ministry of the Environment (MoE) plays a far less important role than METI in the PV policy making. In fact, it is merely involved in the relationship with local governments, but only marginally with the national strategy on renewable and solar energy.

The *Alternative Energy Act* of 1980 established the *New Energy Development Organization* (hereinafter NEDO), as a quasi-governmental organization responsible for industrial and environmental technology R&D management, and for supporting the government in research funding distribution to universities, public laboratories, and the industry.[206] The same act also established a "Special Account for Alternative Energy Development", as a special fund exclusively dedicated to renewable energy development, whose revenues derived from electricity tax and the tax on coal use. Moreover, the *New Energy Foundation* (NEF) is the organization responsible for market development, and incorporates among others a Solar

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[202] Mowery, Rosenberg, *op. cit.:* 226

[203] *e.g.,* The National Institute of Advanced Industrial Science and Technology (AIST).

[204] Mowery, Rosenberg, *op. cit.:* 227

[205] METI was created with the split of the Ministry of Commerce and Industry in May 1949. METI has been responsible not only in the areas of exports and imports but also for all domestic industries and businesses not specifically covered by other ministries in the areas of investment in plant and equipment, pollution control, energy and power, some aspects of foreign economic assistance, and consumer complaints. METI has served as an architect of industrial policy, an arbiter on industrial problems and disputes, and a regulator. A major objective of the ministry has been to strengthen the country's industrial base. It has not managed Japanese trade and industry along the lines of a centrally planned economy, but it has provided industries with administrative guidance and other direction, both formal and informal, on modernization, technology, investments in new plants and equipment, and domestic and foreign competition. The close relationship between METI and Japanese industry has led to foreign trade policy that often complements the ministry's efforts to strengthen domestic manufacturing interests.

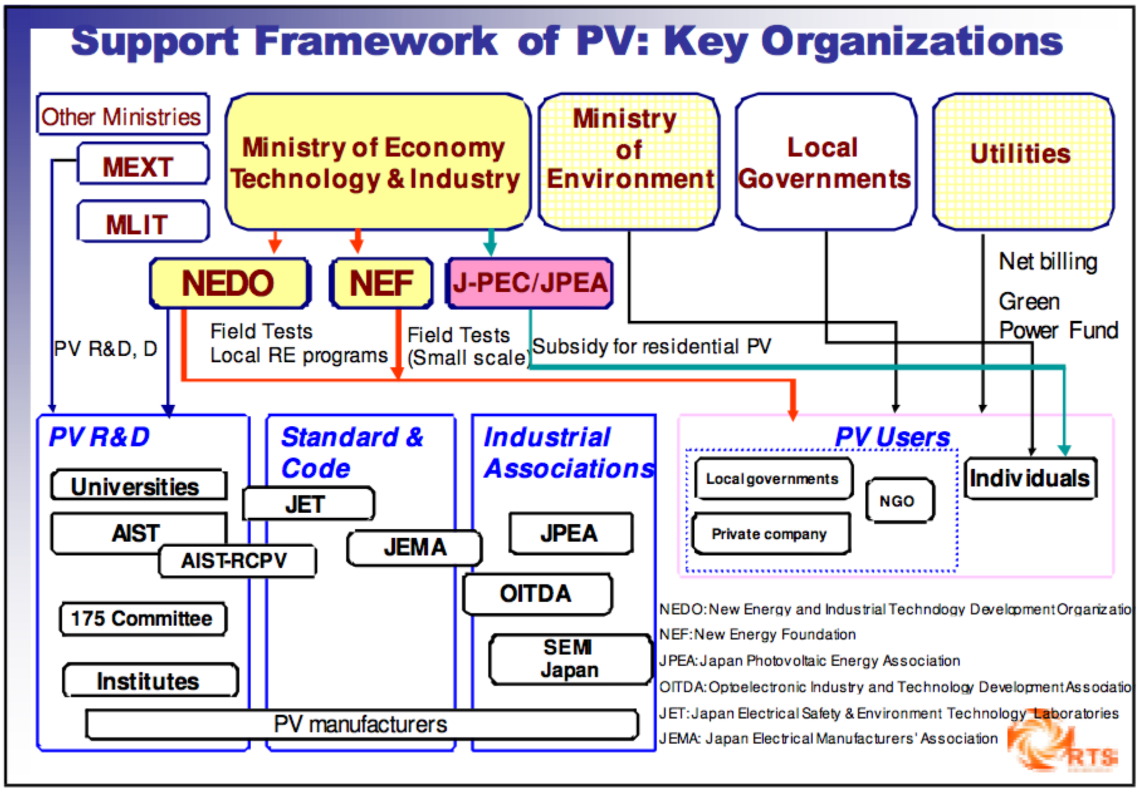
[206] http://www.nedo.go.jp/kankobutsu/pamphlets/kouhou/2008gaiyo_e/95_150.pdf

Energy Committee. Finally, it is worth mentioning the *METI Committee on Alternative Energy Policy*, which consists of university professors and industry representatives, and constitutes a very important organization in the Japanese solar energy policy landscape. In fact, it is the Committee who recommended in 1990 the establishment of incentive policies to enhance alternative energy deployment.

It is worth mentioning the role that METI has played in the relationship with national companies from the postwar period through today. Since the 1950s, Japanese government has sponsored research collaboration among firms and the close relationship between METI and Japanese industry has been strong till the 1970s, when the declining significance of METI to Japanese companies made it a far less powerful agency. In fact, the policies aimed at promoting domestic industry and protecting it from international competition were stronger in the 1950s and 1960s, but as industry became stronger and as METI lost some of its policy tools, such as control over allocation of foreign exchange, METI's policies also changed. During the 1980s, METI was forced to liberalize import policies, despite its traditional protectionist focus, and the ministry helped to craft a number of market-opening and import promoting measures, including the creation of an import promotion office within the ministry.

In conclusion, the close relationship between METI and the industry allowed the Ministry to play an important role in fostering more open markets, although a conflict remained between the need to open markets and the desire to continue promoting new and growing domestic industries. METI facilitated the early development of nearly all major Japanese industries by providing protection from import competition, technological intelligence, and help in licensing foreign technology.

Figure 2.14 Key organizations for PV support framework.



Source: I. Kaizuka, IEA PVPS Workshop March 2009

2.6.1 Japanese Solar Technology Policy

The cornerstone of Japanese energy technology policy is represented by the "*Sunshine Program"*, a national long-term R&D project that was launched by the government in 1974 in response to the first Oil Crisis aiming at providing substantial amount of new non-fossil fuel energy by 2000.[207] According to the Agency of Natural Resources and Energy of the METI, Japan's *Sunshine Program* was intended at improving the country's vulnerable energy supply structure through the development of new energy technologies.[208]

The Sunshine Program formed the backbone for both private and public investment activities in the development of alternative energy technologies. It conducted comprehensive RD&D

[207] The budget initially allocated to the Sunshine Program was ¥ 2.5 billion (approximately $20 million based on exchange rate of 120JPY/USD). In 1973, the total R&D energy funding was ¥ 400 million, rising to over ¥ 80 billion in FY1980.

[208] METI, Agency of Natural Resources and Energy (1991). "Energy in Japan – Facts and Figures", Tokyo.

activity in solar energy including photovoltaics and also solar thermal generation, and solar heating & cooling, and other renewable technologies.[209]

As for PV technology, METI started development under the *Sunshine Program*, with the aim of inducing vigorous industry investment in PV RD&D leading to an increase in industry's PV technology knowledge stock, as well as stimulating cross-sectoral technology spillovers. The principal objectives of the Program were to continue PV material and cell development and to stimulate PV market expansion so that large-scale production benefits could be exploited. The interim evaluation of research and development activities on photovoltaic power generation under the *Sunshine Program* was carried out by a *Policy Technological Subcommittee* every four years, where results were evaluated and new targets were set for development during the next term.

Figure 2.15 shows trends in Japan's R&D expenditure for PV R&D by both the *Sunshine Program* and the industry over the period 1974 - 1995. It can be noted that both R&D expenditure by PV companies and government R&D expenditure patterns on the PV field have been broadly similar over the observed period. Total spending has been increasing dramatically since 1980, except for a period of low expenditure between 1986 and 1990. The growth in 1980 coincided with the recommendation by the *Industrial Technology Council* in 1979, an advisory body of METI, to accelerate PV R&D as a priority project under the *Sunshine Program*. In the first mid-1990s, private sector spending on solar energy technologies nearly doubled, and public spending increased too, even though less dramatically.[210] It is interesting to note that this public spending increase coincided with METI's policy under the *New Sunshine Program,* which started in 1993 and accelerated PV R&D activities as a priority project under the global environmental concerns about consequences of climate change. The New Sunshine Program ended in 2000.

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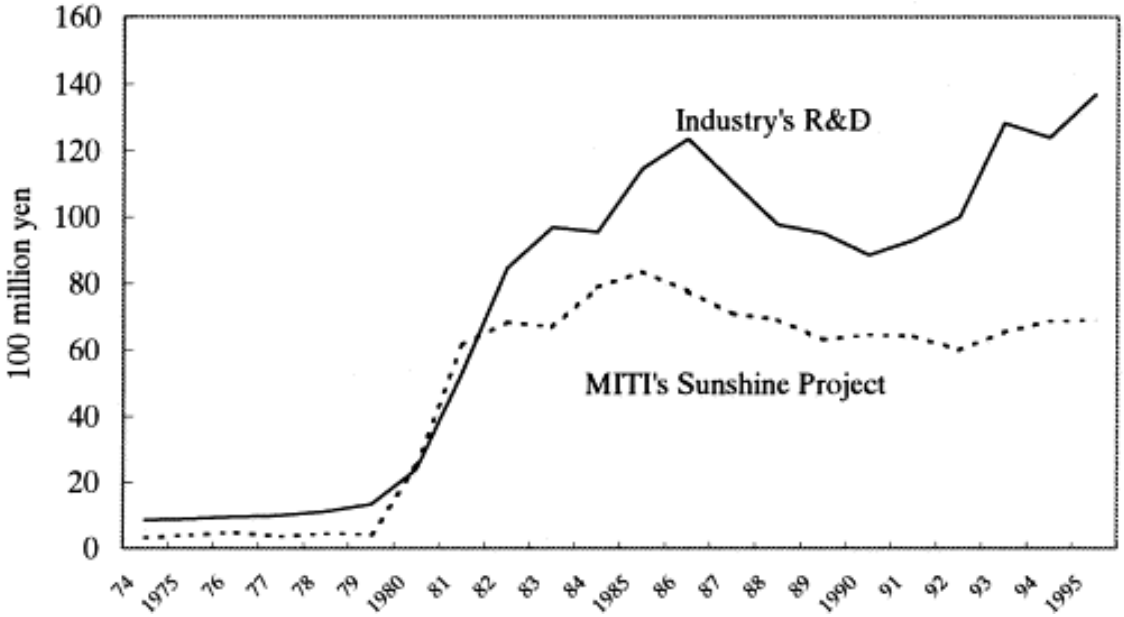
[209] Geothermal energy, coal liquefaction and gasification, hydrogen energy, wind, biomass and ocean power.

[210] OECD/IEA (2004), *op. cit.: 59*

Figure 2.15 Trends in R&D expenditure for PV in Japan (1974 – 1995)*.



* At 1985 fixed prices.

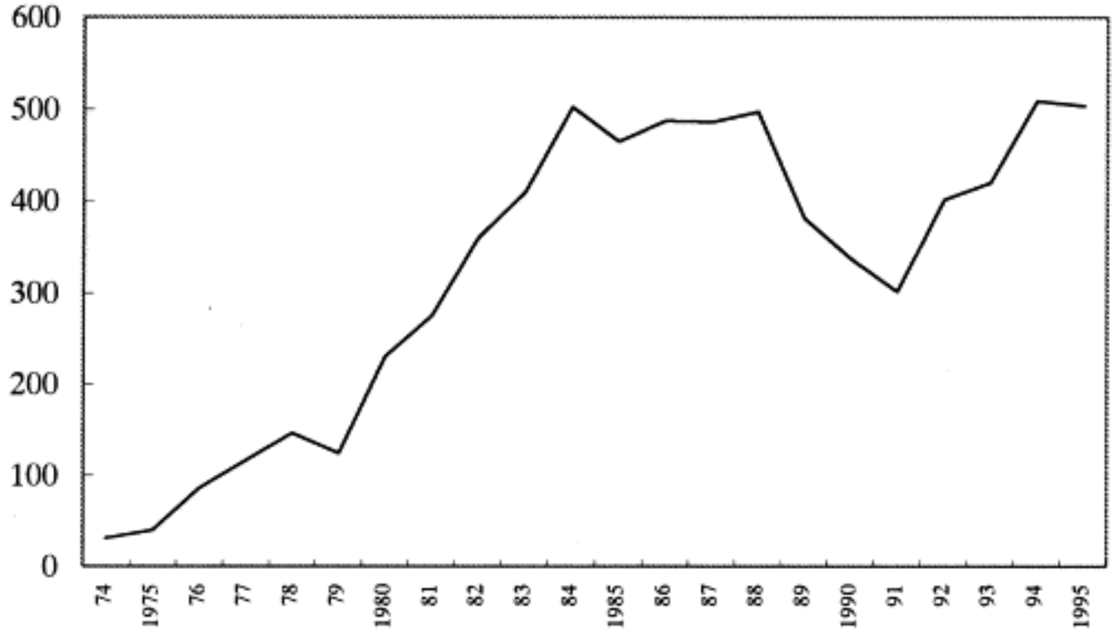
Source: Watanabe *et al.* (2000)

Vigorous PV R&D expenditure and the resulting technology knowledge stock can be considered as the consequence of a specific technology-push policy. Such R&D expenditure and consequently technology stock are expected to generate a number of patent applications in the field of PV R&D. Figure 2.16 summarizes trends in the number of PV patent applications submitted by the eight leading Japanese firms from 1974 to 1995 (Sharp, Sanyo, Kyocera, Kaneka, Fuji, Hitachi, Mitsubishi, Sumitomo).

If we compare figure 2.15 with figure 2.16 it can be noted a correlation between the patent curve and the R&D curve, meaning that R&D expenditure prove statistically to make the most significant contribution to PV patent applications followed by technology knowledge stock. "In many firms not only technology knowledge stock of proprietary R&D but also assimilated spillover technology displays a statistically significant contribution to PV patent applications".[211] Inter-firm technology spillover is the result of inter-firm collaboration stimulated by the Japanese government, such as the case of MITI establishing in 1990 a R&D consortium for PV development called the "Photovoltaic Power Generation Technology Research Association" (PVTEC).

[211] Watanabe *et al*. (2000), *Technovation* 20: 306

Figure 2.16 Trends in the number of PV patent applications in Japanese industry (1974 -1995).

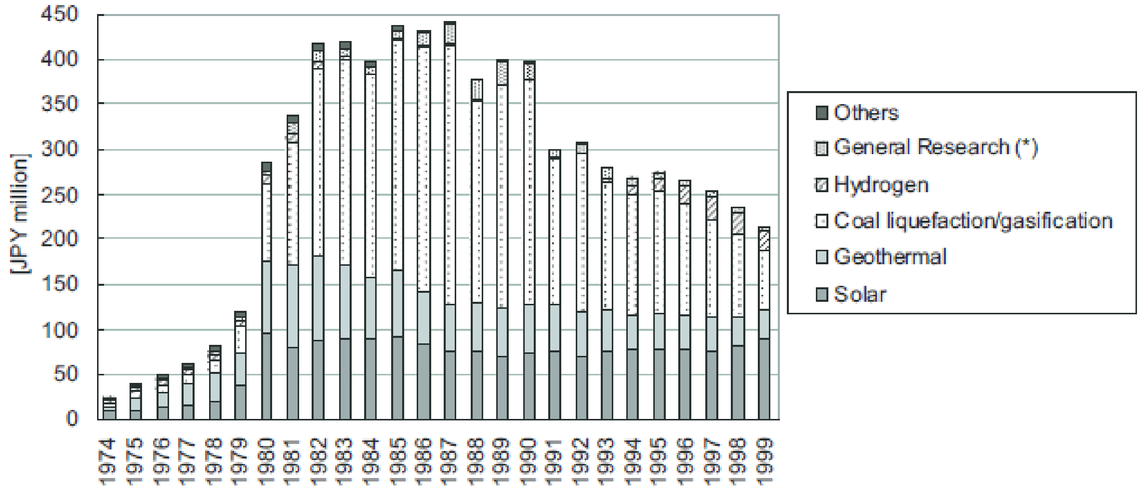


Source: Watanabe *et al*. (2000)

With the second Oil Crisis of 1979 the Japanese government was even more interested in investing in alternative energy and the target and funding for the *Sunshine Program* were intensified. As already observed, a "Special Account for Alternative Energy Development" was established, and this constituted a very important step for the development of renewable energy technology, because most of the budget of the *Sunshine Program* came from this protected source of funding that was based on the tax revenues on electricity and coal. As for the PV budget, a large part of it came from the Special Account, mainly from the revenue of the electricity tax, only in part from the coal tax revenue, and some from the general revenue on RD&D.

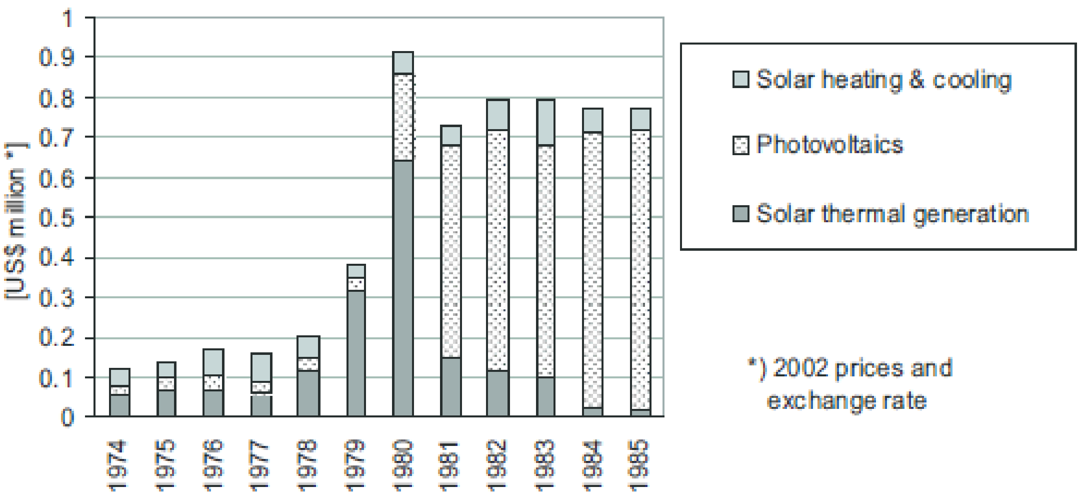
In the 1970s the focus of the *Sunshine Program* was mainly on solar thermal generation technology because it was considered as much more promising among other solar technologies, whereas PV was still considered too expansive and intended more as an alternative technology for small-size projects. Eventually solar thermal generation failed as performance of two demonstration projects in the late 1970s was disappointing, mainly due to characteristics of sunlight in Japan that did not satisfy the CSP need for direct solar irradiation, thus the focus shifted from CSP to PV. Therefore, the budget for PV in 1981 was suddenly expanded absorbing most part of the budget allocated the previous year to RD&D on CSP, and PV reached an abundant and stable budget amounting at around $6 billion all along the 1980s and 1990s (Fig. 2.17 and 2.18).

Figure 2.17 Distribution of expenditure under the Sunshine Program (1974 - 1999).



Source: Kimura, Suzuki (2006)

Figure 2.18 Budget for solar energy technology under the Sunshine Program (1974 - 1985).



Source: Kimura, Suzuki (2006)

Finally, it is worth noting that Japan's share of national renewable energy RD&D budgets allocated to PV technology in the period 1990 - 2002 was 60%. This percentage corresponded to the average budget of $66 millions allocated to PV by the Japanese government in the same period, that was higher than that allocated by Germany ($40 millions) but lower than that allocated by the United States ($77 millions).[212]

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[212] OECD/IEA (2004), *op. cit.*: 56-57

2.6.1.1 Research and Development Tax Credit System

In Japan, R&D tax credit system is different from that of Germany and the US as per general (non-incentive) provisions. Under the Japanese corporate income tax legislation, expenditure on research and development may be either deducted or amortized and this is an option for the taxpayers. An exception was introduced by the 2010 tax reform, where a new group taxation regime has been established, which is applicable to domestic companies that are wholly owned[213] by either a domestic company, foreign company or individual (group companies). Although the tax consolidation system is applied upon election by the taxpayer in case of a domestic company wholly owned by another domestic company, the group taxation regime automatically applies to group companies.

As for a definition of R&D expense, Japanese legislation considers experiment and research expense, those outlaid for manufacturing new products or inventing new technologies; and development expense, those outlaid for market exploitation or starting a new enterprise. Besides this distinction there is no difference as regards tax treatment of pure research costs vis-à-vis development costs.

As far as specific incentives for R&D expenditure are concerned, in 2010 Japan decided to review the Special Taxation Measures Law. Under the 2010 tax reform, 41 incentives for national tax purpose have been abolished or reviewed, among which tax credit for R&D expenditure whose applicable period will be extended for two years. Two major tax incentives for R&D costs exists in Japan. The first is a special depreciation of maximum 50% for companies on equipment used for development research (art. 44-3 of Special Taxation Measures Law). This tax incentive applies to the acquisition cost or manufacturing cost of certain equipment and instruments that are mainly used for development research by a Japanese corporation without restrictions on its size. Development research means experiment and research particularly carried out for the manufacture of new products, or the invention of new technologies, or also the significant improvement of technologies that have been already commercialized (art. 28-6 of Special Taxation Measures Law Enforcement Orders). Whereas for general (non-incentive) provisions the territorialization issue does not apply, as for this specific R&D tax incentive some restrictions applies and the incentive is not available unless R&D is performed in Japan (intramural R&D expenditure).

The second tax incentive for R&D costs in Japan is the special tax credit of 3% to 5%[214] concerning industry-government-academia joint or contract research (art. 42-4, par. 3 of Special Taxation Measures Law). This incentive applies to experiment and research expense concerning experiment and research, jointly carried out with, or contracted to national experimental and research institutes or universities (art. 42-4, par. 12 of Special Taxation Measures Law). Moreover, this incentive is available in case of subcontracted research only if

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[213] Stocks owned by employees under the stock option incentive plan or similar schemes for less than 5% of the total stocks are ignored to determine the 100% ownership.

[214] The rate of credit will be reduced to 2% to 4% from the accounting year starting on or after April 1, 2006.

the research is subcontracted to certain institutions such as universities or experimental and research institutions prescribed in article 27-4 of Special Taxation Measures Law Enforcement Orders, and if the research is approved by the Minister who has jurisdiction over the business concerning technologies targeted by the research.

2.6.1.2 Patent Law and Policy

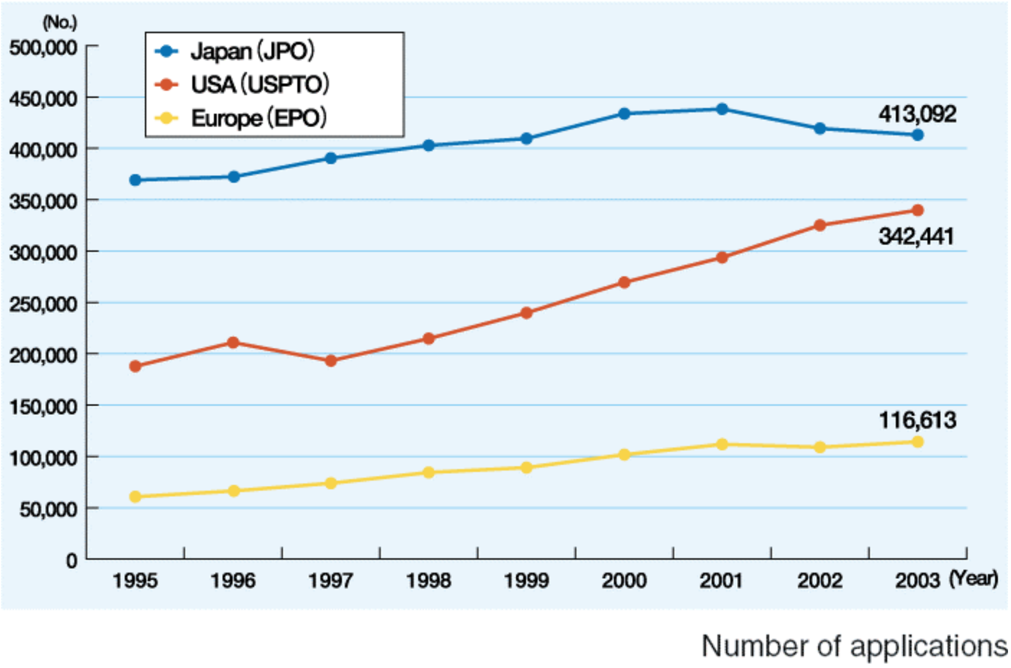
The patent system in Japan was initially established in 1885, mainly based on French and US laws. Since then it has been modified several times and it is now fairly similar to that of the US and Europe, but still retains two important differences.

In the US and in Europe there is a strong emphasis on the *inventive step* and on the *novelty* of any invention. Inventors are required to submit a comprehensive overview of all the prior art so that the examiner can evaluate if the invention is really "non-obvious" to someone with an average knowledge in the field and with access to public information. This discourages filing patent applications that only introduce minor modifications to existing products, thus enforcing a stronger protection for the original inventor and for the assignees. Also, in the US and in Europe there is virtually no limit to the number of *claims* in a single patent application, with the only difference being the fee required to file the application which is proportional to the number of claims. In Japan instead, the patent law is designed to encourage industrial dissemination of new products by allowing even small incremental modifications to be patented, with much less emphasis on novelty. Moreover, patents in Japan are only allowed to describe a very narrow range of processes, and therefore they may only contain a very small number of claims (basically, one).

The combination of these two factors encourages Japanese industry to submit a large number of patents, which is likely the major reason for the disproportionately larger number of overall PV patents applications filed in Japan with respect to those filed in Europe and in the US.

Figure 2.19 illustrates a historical comparison of patent applications in all fields in Europe, the US and Japan from 1995 to 2003, showing the described trend.

Figure 2.19 Comparison of the number of patent applications in Europe, the US, and Japan.

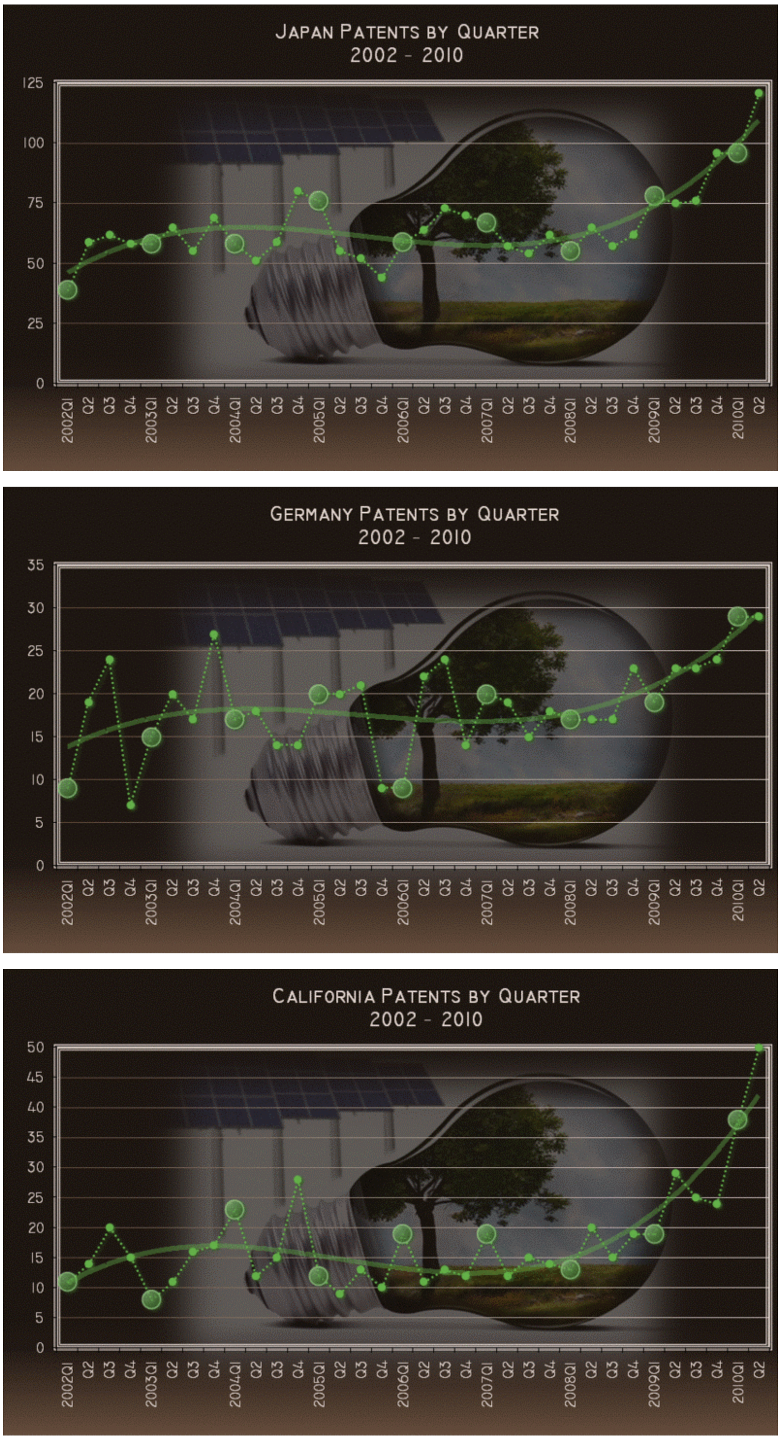


Source: The Japan Patent Office
(http://www.meti.go.jp/english/aboutmeti/data/aOrganizatione/keizai/tokkyo/01.htm)

Figure 2.20 compares the renewable energy patents granted by the United States Patent and Trademark (USPTO) to the three investigated countries from 2002 to 2010. As shown below, Japan led the non-US holders of US renewable energy patents, and the individual US states with 124, up three over the second quarter, and up 48 over the same period in 2009, to claim the geographical renewable energy patent crown. California had 46 renewable energy patents, down four from the second quarter and up 21 over 2009. Germany was down one from the second quarter, and up six from 2009, at 28.

Given the considerations above, it is clear that, even though patent applications are proportional to the underlying research activity, it is difficult to perform a straight comparison among countries with different patent policies.

Figure 2.20 Comparison of renewable energy patents granted in Japan, Germany, and California (2002 – 2010).



Source: Clean Energy Patent Growth Index (2009) Cleantech Group, http://www.cepgi.typepad.com/

2.6.2 Japanese Solar Energy Policy

Several drivers have contributed to the adoption of Japanese energy policies and promotion policies in the PV field. First, the 20-years of PV technology development under the Sunshine Program produced a very important accumulation of knowledge and experience and thus improving PV's efficiency and economics. Second, the considerable effort made by Japanese PV industry to invest in in-house technology innovation, and also its role in lobbying to induce governmental support for PV. Third, climate change which suddenly became prominent in the late 1980s leading to an unprecedented environmental awareness both by the government, which resulted in ambitious PV targets, and by energy consumers, which were willing to face high costs for the installation of PV.

In the early 1990s, three different market-pull policies for PV were established by the Japanese government and the electric power companies, i.e.: an investment subsidy program for residential PV systems (Sec. 2.6.2.1); a voluntary net metering program (Sec. 2.6.2.2); and a renewable portfolio standard regulation (Sec. 2.6.2.3).

2.6.2.1 Japanese Financial Incentives for Residential PV

A "*Residential PV System Dissemination Program*" was established in 1994 and ended in 2005. This program consisted in investment subsidies for the installation of residential PV systems, similar to German "1,000 Roofs Program" of 1991[215]. METI was aware that a subsidy would be necessary in the first stage of the market creation as a stimulus that would cover the high up-front cost of the installation of PV panels. This would help the industry in a "virtuous cycle" of increased demand, investments in new production facilities and further cost reduction by economies of scale, which in turn would further increase demand. But, the adoption of such a subsidy was not an easy task, and the Minister of Finance (MOF) was initially reluctant to accept the program. Nevertheless, different factors have affected METI's decision towards the adoption of this market-pull policy. First, there were high expectations that the cost of PV production would have decreased thanks to learning effects. Second, METI and NEDO were under pressure to deploy renewable energies because despite twenty years of R&D investment through the *Sunshine Program* none of the technologies had yet entered the market. Third, there were expectations that consumers would have invested in PV technology even though the payback period of the installation cost was calculated to be longer than the expected lifetime of PV, and besides subsidies and revenues from the net metering

[215] Lessons learned from German "1,000 Roofs Program" were applied in Japan, with some differences in the amount of the initial subsidy. In Japan the program provided rebates for up to 50% of the investment cost, whereas in Germany it was 60% of the investment cost.

system.[216] Fourth, the Special Account for Alternative Energy Development was a key budgetary source of the program, as it was for the Sunshine Program. Without such a source of funding the METI would have been deprived of the necessary negotiation card to play with MOF in order to start this subsidy program.

In sum, METI decided to take the risk and launched the program in 1994 calling it "*70,000 Roofs Program*" with an initial budget of ¥2 billion (approx. $17 million)[217] to provide 50%[218] of the investment cost (Tab. 2.7). The subsidy program attracted much more consumers than expected, and the following year it was expanded with an increased budget of ¥3.3 billion (approx. $27.5 million), and over 5,000 consumers applied. The program grew steadily and in 2004 it reached more than 60,000 applicants and almost 55,000 installations. The subsidy rate was structured to gradually decrease, from 50% in 1994 to only 3% of the investment cost in 2005, the final year of the program.

Table 2.7 Development of the subsidy program for residential PV systems (1994 – 2005).

Fiscal Year	Budget [JPY billion]	Number of: Applicants	Installations	Installed capacity [kW]	Subsidy rate	Average price of PV per kW [JPY million /kW]
1994	2.0	1,066	539	1,900	50%	2.00
1995	3.3	5,432	1,065	3,900	50%	1.43
1996	4.1	11,192	1,986	7,500	50%	1.17
1997	11.1	8,329	5,654	19,486	up to one third	1.03
1998	14.1	n.a.	6,352	24,123	up to one third	1.02
1999	16.4	n.a.	15,879	57,693	up to one third	0.96
2000	14.5	25,741	20,877	74,381	1st) JPY 270,000 /kW 2nd) JPY 180,000 /kW 3rd) JPY 150,000 /kW	0.87
2001	23.5	29,389	25,151	90,997	JPY 120,000 /kW	0.79
2002	23.2	n.a.	38,262	141,438	JPY 100,000 /kW	0.73
2003	10.5	52,863	46,760	173,687	JPY 90,000 /kW	0.68
2004	5.3	61,407	54,475	200,155	JPY 45,000 /kW	0.65
2005	2.6	39,643	--	--	JPY 20,000 /kW	0.64

Source: RTS Corp., *PV Market 2006: 2005 Review*

Figure 2.21 shows that over the 11 years of the program duration, subsidies and the PV prices[219] have both declined, while demand increased dramatically. If we consider that a total of 72,825 homes were solarized with PV in 2005, half of which with subsidies, it is surprising

[216] O. Kimura, T. Suzuki (2006), "30 years of solar energy development in Japan: co-evolution process of technology policies and the market": 14-15

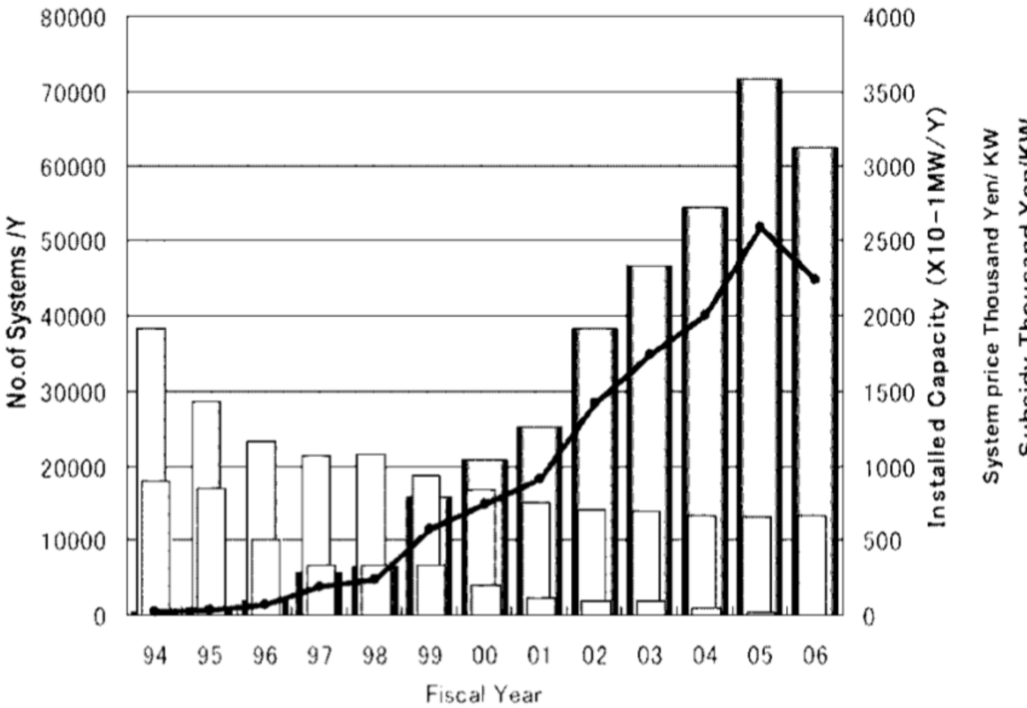
[217] Based on exchange rate of 120JPY/USD.

[218] The average installed price was $20.00/watt and the subsidy was $9.00/watt.

[219] The installed price of a residential grid-connected PV system has declined from nearly $11/W in 1995 to less than $7/W in 2001.

that in 2006 as many as 62,544 homes were introduced totally without subsidies.[220] We can therefore imply that with the end of the subsidy program the attitude of consumers had not changed so much. In fact, if it is true that the subsidy reduction had been compensated by the decrease of PV system cost, PV electricity was much more expensive than the residential electricity rate with the subsidy.

Figure 2.21 Historical trend of the Japanese PV Roof Top Program (1994 – 2005).



Source: J. Honda (2007)

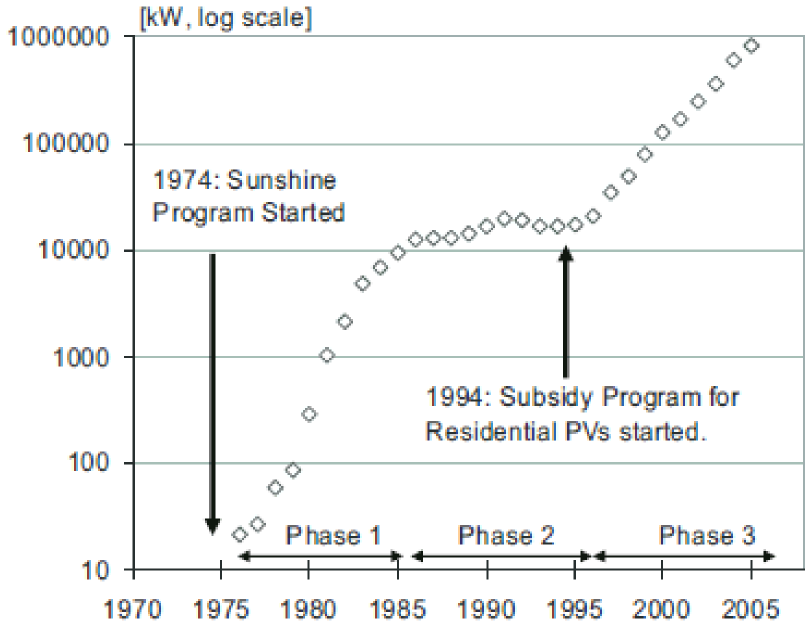
This surprising feature has been explained by a survey conducted in 1999 by Iuchi of the Central Research Institute of Electric Power Industry. According to the survey, participants applying to the program had higher income compared to the reference group. In fact, when asked the motivations to purchase PV, more than 90% of the participants pointed “contribution to protecting the global environment”, and about 60% pointed “reducing electricity bills”. In addition, more than 90% pointed the “governmental subsidy” as another motivation. In Iuchi’s opinion, the results show that PV technology was accepted by high-

[220] J. Honda (2009), “History of Photovoltaic Industry Development in Japan”: 118-123

income consumers with high environmental consciousness, who are rather indifferent to the cost of installing PV.[221]

The expectations made by METI on the eve of the adoption of the "*Residential PV System Dissemination Program*" were fully respected and from 2006 onwards the Japanese households continued investing in PV installations besides the lack of subsidies. From figure 2.22 it stands clear that from an economic standpoint the program had benefited the market of solar cell production. The program prompted rapid growth of the PV market in Japan and spurred supply-chain development by manufacturers, integrators, and installers. In conclusion, both from a policy analysis and economic perspective, it can be inferred that the 1994 "*Residential PV System Dissemination Program*" contributed considerably to support PV technology deployment.

Figure 2.22 Trend of solar cells production in Japan (1976-2005).



Source: Kimura, Suzuki (2006)

Considering the very good results in terns of PV installation of the first "*Residential PV System Dissemination Program*", METI decided to reintroduce a subsidy for residential and commercial PV installations, and made it in response to the "Fukuda vision". In June 2008, the Japanese Prime Minister Fukuda presented a plan to achieve a 50% reduction of global emissions by 2050. The "Fukuda vision" significantly bolstered Japan's attitude towards PV. The "Action Plan for Achieving a Low-Carbon Society" was approved by the cabinet in July

[221] Iuchi M., Konakayama A., Ohkawara T., Tsuchiya T. (1996), "An empirical analysis of consumer decision making processes on setting up residential photovoltaic systems". CRIEPI Report Y96006, Central Research Institute of Electric Power Industry. (in Japanese)

2008, and set new national targets for cumulative installed PV capacity at 14 GW by 2020 and 53 GW by 2030.

Despite the withdrawal of the earlier support subsidy in 2005 the PV market in Japan remained mostly a residential one (80% of installed capacity in Japan). In fact, although METI extended the subsidies to the commercial and public sectors[222], under the new residential subsidy framework of January 2009, METI decided to strongly subsidize residential systems of up to 10 kW, providing ¥70,000/kW ($774/kW).[223]

2.6.2.2 The Net Metering Program

The net metering program was introduced in Japan in 1992 under the name of "Surplus Electricity Purchase Menu" as a voluntary action by the electric power industry to enhance renewable energy installations by consumers. The electric power companies had been making considerable efforts on R&D activities on renewable energies and PV since the inception of the Sunshine Program; therefore, during the 1980s they were reluctant to deploying PV and other renewable energies as practical power sources due to reliability and economic reasons.

The adoption of the net metering system needs to be considered within the framework of the 1990 "Energy Outlook" policy statement by the MITI in which it adopted an optimistic deployment scenario of PV power (250MW by 2000, 4,600MW by 2010 of PV cumulative installed capacity)[224], with the aim of reducing emissions. The ambitious PV target set by the government contributed to change the reluctant attitude of the electric power industry towards PV deployment that finally resulted in the adoption of the net metering system in 1992.

Since the net metering program is a mere voluntary program by the major electric power companies, and not an obligation by the government, as soon as the utilities faced market liberalization starting from the mid-1990s[225], they got frustrated by the increasing burden of the net-metering system that went beyond 400 MWh in 2004.[226]

This situation made PV market development in Japan problematic, since electric power companies could reconsider weather to maintain the current net-metering program. Nevertheless, this stalemate was interrupted in November 2009 with the adoption of the *"Buyback Program for Photovoltaic Generation",* a new net metering system, which was no

[222] The subsidy covers 1/3 of installation costs for commercial sector and ½ for the public sector.

[223] The new program was aimed at supporting both installation and equipment costs and for FY 2008 it appropriated a budget of ¥9 billion ($99.5 million), and a further ¥20 billion ($222 million) was appropriated for FY 2009.

[224] In 1994 the "Energy Outlook" was revised and the PV targets were incremented (400MW by 2000, and 4,820 by 2010).

[225] For a more comprehensive analysis of the Japanese energy market liberalization see M. Goto & M. ,Yajima, "A new stage of electricity liberalization in Japan: Issue and expectations", in *Electricity Market Reform, an International Perspective*, F. Sioshansi & W. Pfaffenberger ed., Elsevier, Oxford, 2005: 617-643

[226] Kimura, Suzuki, *op. cit.:* 18-19

longer based on voluntary actions by electric power companies, but it was instead imposed by the government.[227] The new net metering program applies only to surplus electricity generated using PV power systems. The buyback price was set at ¥48/kWh for residential use, whereas for factories, business establishments and schools it is set lower at ¥24/kWh in view of their high subsidy rates.[228] Buybacks will continue for 10 years after the start of the program until 2020.[229]

2.6.2.3 The Renewable Portfolio Standard

The third market-pull policy is the renewable portfolio standard (RPS), introduced in Japan through the "*Special Measures Law on the Use of New Energy by Electric Utilities*" (hereinafter RPS Law). It was enacted in June 2002 and came into force on April 2003 with the aim of furthering the use of renewable energy by imposing an annual obligation on electricity retailers to use a certain amount of electricity from renewable energy sources.

The RPS Law in Japan requires that approximately 1.35% of each retail supplier's electricity sales in FY2010 come from electricity generated from renewable energy sources, including PV.[230] Moreover, to be certified as a renewable energy source, the generated electricity must be sold to the grid, meaning that electricity generated for self-use is ineligible.[231] Furthermore, existing plants are also eligible in the renewable portfolio standard program.

Since the beginning of the RPS scheme the total amount of renewable energy sources tended to exceed the targets set, e.g., electricity from renewable energy sources target in FY2003 was set at 3.3 TWh,[232] and 4.0 TWh were supplied of which 0.15 TWh by PV, thus exceeding the actual target by 0.7 TWh (Fig. 2.23). Therefore, in 2006 the Japanese government decided to revise the targets upward by 4.0 TWh from 2006 to 2009 to reach 12.20 TWh in FY2010. The new RPS target was set in March 2007 for FY2014 and established the goal at 16 TWh,

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[227] "Law on the Promotion of the Use of Non-fossil Energy Sources and Effective Use of Fossil Energy Materials by Energy Suppliers" (Law No 72 of 2009).

[228] Both these prices are about twice as high as the voluntary buyback prices. Buyback prices are to be reduced by about a half in five years, in line with the progress in introduction of panels and their price trends.

[229] http://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/ref2002.pdf (accessed on March 2, 2009).

[230] The targets are low compared to those in the United States, partly because large-scale hydropower and conventional types of geothermal are considered ineligible under the RPS scheme and also because a large amount of electricity from biomass is consumed for self-use.

[231] K. Nishio, H. Asano (2006), "Supply amount and marginal price of renewable electricity under the renewable portfolio standard in Japan", *Energy Policy* 34: 2373-2387

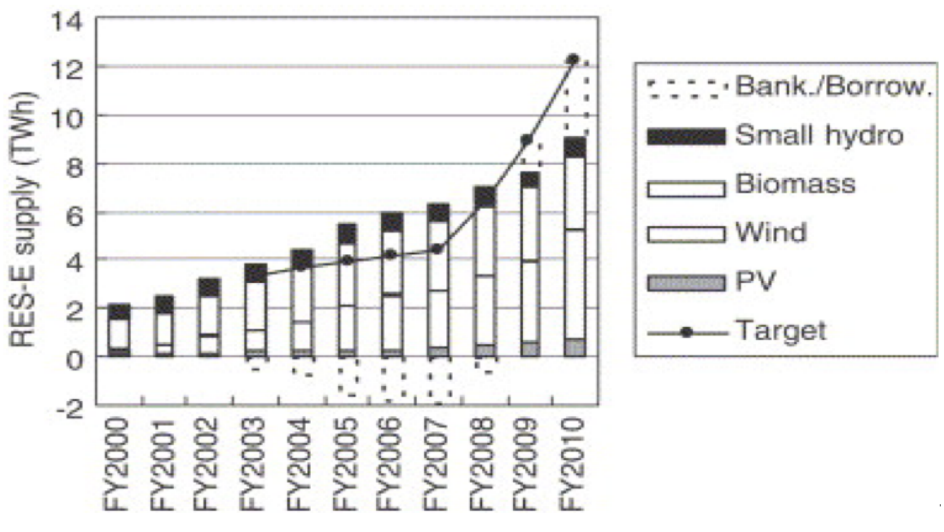
[232] Set according to the Adjustment Method for the Obligation Amount Transitional Measures: as transitional measures, the adjustment method has been determined in order to provide an adjustment over the seven years following enactment of the law (i.e., leading up to the year before 2010) that set practical implementation targets for each retailer based on their actual prior results; "Post Adjustment Obligation Amount" = "Pre Adjustment Obligation Amount"/ "Usage Target Rate" * "Adjusted Usage Target Rate".

corresponding to 1.63% of each retail supplier's electricity sales. A very important new measure for PV sector was introduced in 2007 RPS law amendment whereby electricity generated by PV power will be recognized as twice its value (generating 1 KWh would be counted as 2 KWh) for the period between 2011 and 2014 to encourage PV diffusion.

As with RPS scheme in the United States and Europe, retail suppliers and renewable generators may trade certificates, although in the case of Japan they cannot trade internationally. Also, banking and borrowing of certificates up to 20% of the target are allowed. The maximum price of the certificate is set at 11 ¥/kWh (approx. $9/kWh). Actually, the certificates were traded at a relatively stable price range of around 5¥/kWh (approx. $0.6/kWh from 2003 to 2005). It can be inferred that the renewable market was in a state of excess supply, and that the trade in renewable energy sources remained low partly because of a wait-and-see attitude in the first year of implementation.

Figure 2.23 shows the development of supply of electricity from renewable technologies in Japan from FY2000 to FY2010. It is worth noting that this supply only represents a part of the total renewable electricity generation, since the electricity generated for self-use is excluded because ineligible for the RPS. With regard to the breakdown of the renewable portfolios, in FY2010 PV would get to 1.5 GW providing 0.7 TWh, quite a low number if compared with wind power (2.0 GW providing 4.5 TWh), and biomass power (1.8 GW providing 3.0 TWh).[233] Therefore, it can be inferred that wind power and biomass power from municipal waste are potentially more willing than PV to supply the majority of the total electricity from renewable energy sources under the renewable portfolio standard in Japan.

Figure 2.23 Electricity generation from renewable energy source supply projections based on technology.



Source: Nishio, Asano (2006)

[233] Nishio, Asano, *op. cit.:* 2381

In conlusion, the Japanese RPS policy has not to be underestimated since the most important feature that distinguishes RPS scheme in Japan from RPS in the United States, is that the obligation to produce a defined amount of electricity from renewable energy sources is applied directly to technology suppliers and not on electricity suppliers. This specific characteristic could play an important role in the direction of technology innovation in the renewable energy sector in Japan, and especially in the photovoltaic field.

2.7 Conclusion

In this chapter, our assumption that technology-push and market-pull policies should exist simultaneously has been confirmed by our analysis of technology and energy policies in California, Germany and Japan.

The United States has been triggering the growth of PV industry since the mid-2000s and this is due to a combination of technology-push and market-pull policies in the preceding decades. In the 1970s an important RD&D strategy in the solar field was conducive to the most important technology improvements in the solar cell. In the same years a federal feed-in law and an energy tax act were approved contributing to the installation and generation of photovoltaic energy and fostering the development of a PV industry in the United States. The lack of both technology-push and market-pull policies in the 1980s caused a setback of the US in the global PV market and contributed to cutting it off of the 1990s world PV industry growth that occurred in Japan first and in Germany later. The real turning point in the US PV development history was the mandatory renewable portfolio standards' requirements adopted in the 2000s in most States. California has been taken as a reference for best practices for its unique role in technology innovation both at the public and at the private level, as well as for the functional regulations and strong incentive measures adopted. The Golden State implemented not only a conducive technology-push policy that favored an important industry-university cooperation, but also positive market-pull policies, such as: a demanding quota system, a conducive net metering system, and also a subsidy system for residential and business PV installations that is no doubt one of the most advanced in the United States.

As for Germany, we have tried to demonstrate the role that the considerable amount of public and private investments in solar RD&D since the early 1980s, combined with a favorable national legislation and promotion policies, have played in the development of a flourishing German PV industry triggering PV growth in the 2000s. From the first feed-in tariff law in 1991, which contributed to the creation of an embryonic German PV industry, to the renewable energy law amendment of 2009, many changes occurred not only in the feed-in tariffs structure but also at the industry level. The introduction of tariffs for megawatt-sized plants stimulated the considerable increase in MW installed capacity with obvious implications for the growth of PV industry in Germany. Also, the presence of a well developed network of research centers and universities and a consolidated PV components industry constituted and still contribute important added values to German success. Moreover, tariffs adjusted on the basis of the annual capacity increase have been an important stimulus to PV technology innovation thanks to learning curves effects. Therefore, the German feed-in tariff should be taken as a best practice policy for other countries that might decide to undertake the path towards renewable energies.

In Japan, the considerable investment in technology innovation by the MITI in the mid-1970s provided a stable environment for research and development. However, the government RD&D policy was not enough for the creation of a steady Japanese PV industry that was only established when private RD&D spending by PV industry grew in the first half of the 1990s.

The reasons behind the role of Japan in triggering PV industry growth in the 1990s were due to a combination of technology-push approaches and market-pull policies that have fostered the demand for both PV systems and PV power. The residential subsidy program and the voluntary net metering system constituted important market creation policies that convinced consumers, even after the programs ended, to purchase expensive PV equipments, thus creating a "niche" PV market in Japan. Nevertheless, as we will see, Japan aims at promoting an expert PV industry mainly because of its trade benefits more than for satisfying a domestic demand for solar installations that is mainly residential.

Chapter 3: Photovoltaic Market Development: The Role of Energy and Technology Policies to Support PV Industry

3.1 Introduction

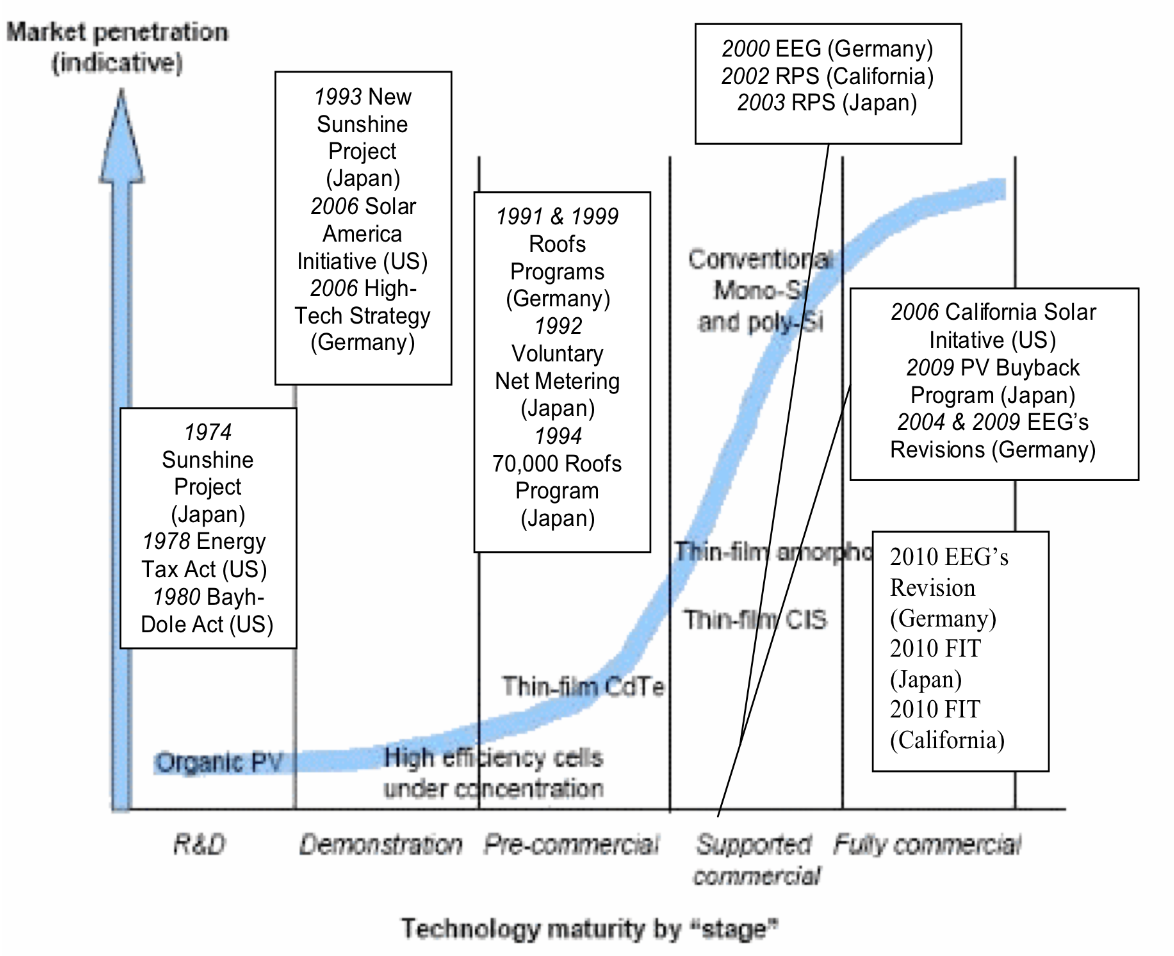
This chapter analyzes the global market of photovoltaic technologies, with a special attention to California, Germany, and Japan, and the effects that technology and energy policies have had on the performance of their leading PV manufacturing companies, and on the share of their domestic and foreign sales.

The chapter is organized as follows: the illustration of the market of PV energy through the analysis of the global installed capacity (Sec. 3.2); the description of top manufacturing PV companies in Germany, Japan, the United States and California (Sec. 3.3); the investigation of the role played, directly or indirectly, by technology-push policies on their national companies' performance (Sec. 3.4); and the analysis of the role that market-pull policies adopted in California, Germany, and Japan played on the performance of their national companies (Sec. 3.5).

The companies in our focus were chosen because they are among the top global PV companies with a longstanding history in the PV market, and they are based in the three countries under analysis. These companies are: one crystalline-silicon PV company, the US SunPower; one thin-film solar company, the US First Solar; and three both silicon and thin-film PV companies: the Japanese Sharp, which manufacturers solar cells as part of a larger product portfolio; the Chinese Suntech, with strong industrial as well as technological connections with the United States; and the German Q-Cells.

The analysis of the diffusion of various PV technologies already described in chapter 1 shows a strong correlation between their technological cycle from RD&D to commercialization, and both the technology and energy policies adopted in California, Germany and Japan described in chapter 2 (Fig. 3.1).

Figure 3.1 PV Market penetration of different PV technologies along with policy drivers.



As observed, the shape of a S-curve does not apply conventionally to PV technologies. PV firms can overcome barriers to technology's performance improvement or stretch the S-curve of a specific technology via new development approaches, in terms of power conversion efficiency or by changing the design of solar cells and panels. A good example is the California's company SunPower that is continuously investing in research and development in order to reach higher architectural standards and higher efficiency levels of its crystalline-silicon solar cells and panels. In this case a mature technology that has dominated the market since the 1950s still offers margins of performance improvements and, therefore, it is continuously attracting investments in RD&D. Going backwards along the S-curve, despite thin-film technologies are in the commercial phase, they are characterized by continuos RD&D investments, and show constant progress in terms of conversion efficiency. A good example is the US company First Solar that is the world leader in the production of CdTe thin-film solar cells, and whose research activity is focused on increasing efficiency of its cells while lowering costs. As for PV cells under concentration (CPV), after many years of intense research activities for increasing efficiency, improving reliability and reducing the manufacturing cost, CPV technology is already competitive in high solar resource regions.[234] Finally, despite much progress has been made in organic PV, continuos RD&D makes this third-generation PV a more and more promising technology.[235]

The aim of this chapter is to analyze the supply side of PV technologies that have already been fully deployed. Thus, we will not take into consideration organic PV, nor CPV, but only the first and second generation of photovoltaics, i.e. the silicon-based and thin-film solar technologies.

Whenever the original financial figures were not available in US$ the corresponding amounts in US$ reported in this chapter were calculated according to the average annual exchange rate published by the US Federal Reserve (http://www.federalreserve.gov/releases/g5a/) for the corresponding year.

3.2 The Market of PV: Global Installed Capacity

For the purpose of investigating global PV installed capacity, in this section we focus mainly on grid-connected PV that has been growing steadily since 2007, and in 2008 and 2009 it accounted for the majority of the total PV installed capacity. This approach is explained by looking at the statistics collection approach used by many national governments that does not account for off-grid facilities.

Since data on PV annual and cumulative installed capacity among different well-respected sources are often contradictory, the European Photovoltaic Industry Association (hereinafter EPIA) for data on Europe and Asia, and the Solar Energy Industries Association (hereinafter SEIA) for data on the United States and California are taken as the major reference sources. In this first section we investigate the PV global market and its main development trends through the years 2008 and 2009. These two years were particularly significant in terms of changes in market capacity and demand for photovoltaics, due to a chianging policy framework and the 2008 economic downturn.

The year 2008 represented a turning point in the PV market history. Despite the sharp drop in prices of solar modules (of up to 30%), the global financial and economic turmoil failed to cause a major PV market crash. The reduction in PV prices occurred gradually and it can be explained first as the result of the decreasing average installed cost of PV due to learning effects. According to a study by the Laurence Berkeley National Laboratory, PV prices in the United States declined from 1998 to 2008 by around 3.6% per year. From 1998 to 2005, the

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[234] http://www.photon-international.com/newsletter/document/34349.pdf

[235] S. Lacey (2010), “Is Organic PV the Future of Solar?”, http://www.renewableenergyworld.com (accessed May 2010).

reduction was due to lower non-module costs (balance of systems, inverters etc.), and from 2007 to 2008, the reduction was due to lower module-costs.[236]

Falling prices were also partly due to an oversupply of cells and modules, which was favored by two factors: the gradual end of polysilicon shortage, and the augmented competition with the entry into the market of new players that generated larger investments in new technologies, as well as increased production by established players. By the end of 2008 the world cumulative installed capacity surpassed 15 GWp[237], and Europe was leading with more than 80% of global annual production, followed by Asia with around 10%[238], and the United States with only 6%. According to EPIA data, in the period 1998-2003 the compound annual growth rate[239] (hereinafter CAGR) of PV global installed capacity was 24%, and in the period 2003-2008 it was much steeper and amounted to 39%.[240]

In short, in 2008 the solar PV industry continued to be one of the world's fastest growing industries and this was due to three PV market development trends. First, the growing attention to building-integrated PV (BIPV), which was still a small but fast-growing segment of the market. Second, utility-scale solar PV power plants (defined as larger than 200 kW)[241] grew considerably. Third, thin-film solar PV technologies increased their share in total installations, and global thin-film production increased by 120% in 2008 to reach 950 MW.

As far as this last trend is concerned, although silicon-based technology was still the most widespread in 2008 (85%), and thin-film technologies (CdTe, CI(G)S, a-Si) occupied a much smaller share (15%), the latter are expected to develop further in the coming years according to EPIA. Each technology presents different characteristics and will cover the needs of different PV market segmentsa and thin-film technologies are more suitable for both large-scale solar plants (due to lower costs), and for BIPV (due to a more flexible design). In 2005, a polysilicon shortage occurred that limited the growth of crystalline technology in the last few years, and offered a great opportunity for the thin-film manufacturers to grow. Although the silicon shortage gradually ended in 2008, this trend was not interrupted, and in 2009 thin-

[236] E.g., in 1998 the average installed cost was $ 10.8/W, whereas in 2007 this was $7.8%/W. R. Wiser *et al*., (2009), "Tracking the Sun II, the Installed Cost of Photovoltaics in the US from 1998-2008", LBNL.

[237] PV power installed is measured in Wp (watt peak) and refers to the nominal power under Standard Test Conditions STC (1000W/m2, 25°C, 1.5 AM). Hereinafter referred to as KW, MW, GW.

[238] Since the mid-2000s, competition characterizes the solar market with new emerging PV countries in the European Union (Italy, France, Belgium, Czech Republic), as well as in Asia (South Korea, China, India, and Taiwan) that are developing their own installed capacity. In Asia, in particular in China and Taiwan, thanks to M&A operations and the entrance of foreign investors, increased steadily their cumulative installed capacity, and India emerged as an aspiring producer of solar PV. In 2008, South Korea was the country that grew faster than other Asian countries, surpassing Japan as for annual installed capacity, followed by China with new 46 MW, and India that added only 40 MW to its annual PV capacity.

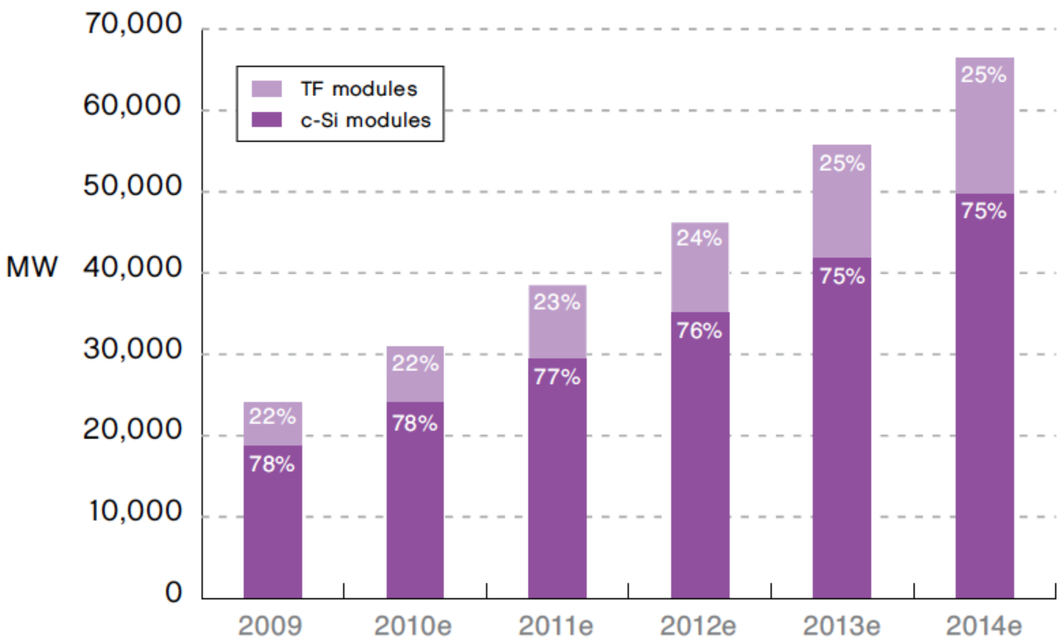
[239] The year-over-year growth rate over a specified period of time.

[240] EPIA (2009b): 4

[241] This definition has been adopted by the REN21 Report, *Renewables Global Status Report*, although the utility-scale PV, also called centralized PV, generally ranges between 2 MW and 1 GW; the commercial building PV, also called distributed generation, ranges from 20 KW to 2 MW; and the residential PV, also called on-site generation, generally has a capacity of less than 20 KW.

film earned an even increased market share. Crystalline-silicon versus thin-film solar cells production share trend is illustrated in figure 3.2 where it is shown that in 2009 thin-film technology grew up to 22% of total PV production, whereas silicon-based technology' share was 78%.[242]. According to EPIA forecasts, in 2013 and 2014 thin-film technologies are expected to get to a share of 25%, equivalent to a quarter of the total PV production capacity outlook.[243]

Figure 3.2 Production capacity outlook: Crystalline Silicon vs. Thin-Film technology.



Source: EPIA (2010a)

The regional distribution of PV production capacities differed significantly depending on the type of technology and its position in the value chain. In 2009, Europe was a strong manufacturer of both the c-Si and thin-film technologies, although it was a market leader in thin-film PV (Q-Cells, Schott Solar, Bosch Solar Energy, Oerlikon Solar, Komax Solar, Arendi). The US was stronger in the thin-film technology especially thanks to First Solar's production that made the US company the top PV company in 2009, and thanks to the contribution of many manufacturing companies (United Solar, Signet Solar, Ascent Solar, Abound Solar), and flourishing start-up companies (Nanosolar, Solyndra, Miasolé). In Asia, Japan also offered better performance in the production of thin-film technology (Sharp, Sanyo), even though many Japanese companies were specialized in silicon-based solar cells production (Mitsubishi Electric, Kyocera). China was an indisputable leader in silicon-based

[242] M. Osborne, "Solar photovoltaic market grew 6% in 2009, says Solarbuzz", www.pv-tech.org.

[243] EPIA (2010c): 24

technologies (Suntech, Trina Solar, JA Solar, Yingli Green Energy, Solarfun Power, Renesola), and so was Taiwan (Gintech Energy, Motech Industry).[244]

In 2009, despite the continuing economic downturn, the PV market grew and the cumulative power installed in the world rose by 46% to 22.9 GW. Nevertheless, the solar industry experienced a storm of market-changing events that altered the competitive landscape. In 2008, the solar market shifted from a supply-constrained to a demand-driven one within a few quarters as a result of two main factors. First, the continuous growth of less expensive thin-film supply as cost per watt ($/W) became the primary driver of project return on investment (ROI). Second, Spain's dramatic decline in demand as overly generous feed-in tariffs were capped in October 2008. Indeed, the most remarkable figure in 2009 compared to 2008 is that Germany surpassed Spain as the country with more MW of annual installed PV capacity. Germany grew from 1.8 GW in 2008 to 3.8 GW in 2009, with an increase of 111% driven by uncertainty about a drop in the feed-in tariffs that actually occurred in April 2010. The Spanish market went down to only 69 MW installed in 2009, the worst year for Spain since 2005. However, Europe was always leading the way with almost 16 GW of cumulative installed capacity in 2009, representing more than 70% of the world cumulative PV power installed at the end of 2009. The European success was mainly due to the impressive growth of Italy with an added annual capacity of 711 MW[245], followed by the Czech Republic (411 MW), Belgium (292 MW) and France (185 MW).

Japan and the US were following behind, and Japan was the third market after Italy in 2009 for new installed capacity (484 MW), followed by the United States (477 MW). In the US the cumulative capacity crossed the 1 GW threshold making 2009 a challenging and transitional year for the country's PV market. Interestingly, in the traditional off-grid US market, grid-tied PV installations grew by 38% in 2009, when some of the largest projects in the world began construction, driven by federal stimulus funds.

Another set of numbers that is worth mentioning comes from Asia, and in particular from China that was until 2009 almost absent from the world's PV market. China made its entry into the top ten world PV manufacturing countries by doubling its PV installed capacity from 145 to 305 MW in 2009. On the other hand, South Korea saw its PV annual installations drop to 168 MW in 2009 after a good year in 2008 with 352 MW of cumulative capacity[246].

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[244] With respect to thin-film production capacities, Europe led with around 30%, whereas the US, Japan, and China each accounted for about 10 to 20% of thin-film manufacturing capacities, and the rest of Asia for 20%. Interestingly, the share of thin-film solar cells in terms of actual production was mainly driven by Cadmium Telluride technology from one single company, the US First Solar. The silicon-based cells and modules segment was dominated by Asian manufacturers, especially Chinese and Taiwanese, with more than 50%. In Japan, c-Si cells and modules counted in 2009 for less than 10%. In Europe, production capacity accounted for almost 20% in c-Si cells and for almost 30% in c-Si modules. In the US, production of c-Si cells and modules accounted for only 5%.

[245] Italy appears in 2009 as one of the most promising markets. As to the dimension of the PV market Italy was at the second-place but with roughly the same size as the US and Japanese markets. This is interesting if we compare it with the position of Italy in the GDP list according to the IMF, where the US is at the fist-place, followed by Japan at the second-place, and Italy follows at the 7th place.

[246] G. Hering, W. P. Hirshman, "Top of the World", *Photon International,* February 2010: 58

Finally, India had 30 MW of annual installed capacity in 2009, of which about 8 MW of ground-mounted systems connected to the grid, and the others being off-grid rural PV.[247]

In conclusion, despite the financial and economic turmoil of 2008, the annual PV market has grown by 18% from 6.1 GW in 2008 to more than 7.2 GW in 2009. Nevertheless, if in the 2-year period 2007-2009 CAGR of PV installed capacity was 55%, the PV capacity growth rate from 2007 to 2008 was steeper than that from 2008 to 2009, 64% and 46% respectively. (Figure 3.3)

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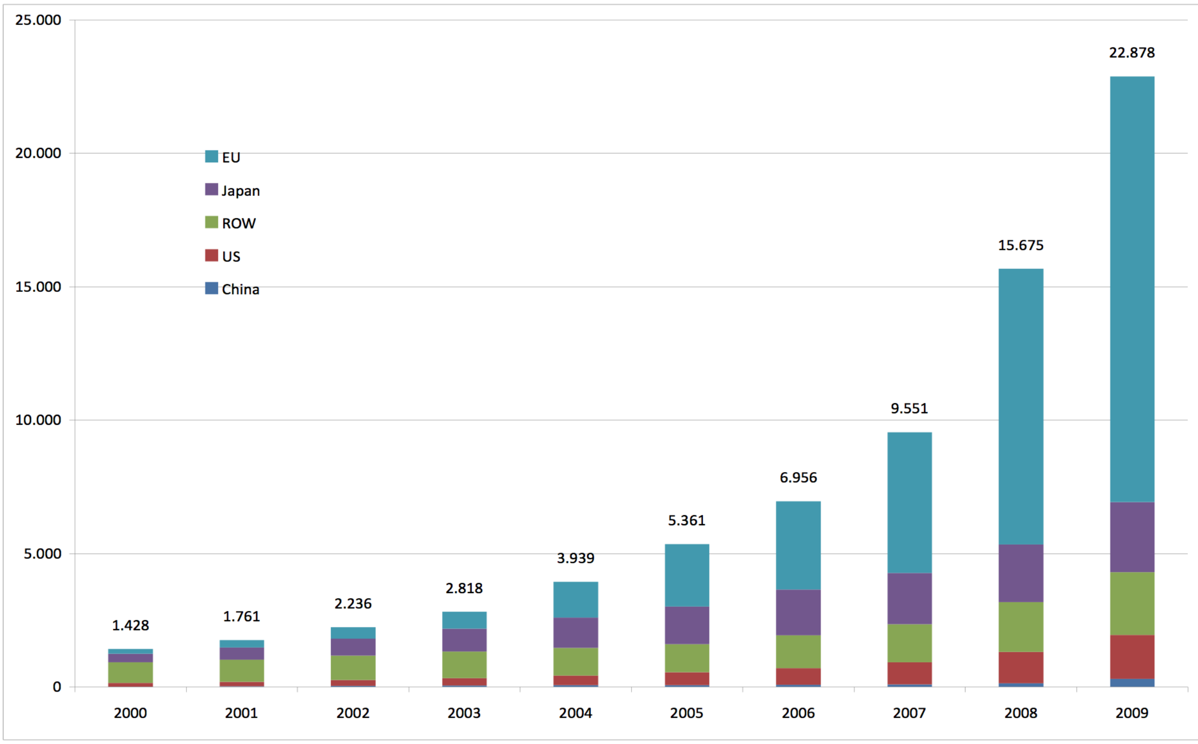
247 "National Solar Mission" launched by the Indian Government in January 2010, targeted 20 GW of installed PV and solar thermal by 2022. E.V.R. Sastry, "PV's ups and downs in India", *Photon International*, February 2010: 208

Figure 3.3 Global Installed PV Cumulative Capacity in MWp (2000 – 2009).



	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
China	19	30	45	55	64	68	80	100	145	305
US	139	168	212	275	365	479	624	831	1.173	1.650
ROW	763	825	913	1.000	1.044	1.051	1.235	1.422	1.870	2.347
Japan	318	452	637	860	1.132	1.422	1.708	1.919	2.149	2.633
EU	189	286	429	628	1.334	2.341	3.309	5.279	10.338	15.943
TOTAL	1.428	1.761	2.236	2.818	3.939	5.361	6.956	9.551	15.675	22.878

Source: EPIA (2010a)

3.3 The Supply Side: Top PV Manufacturers

We now analyze the effects of technology and energy policies from the perspective of the manufacturers of PV technology. We first explain the top world PV companies' rankings from 2001 to 2009.

Table 3.1 Top ten PV global companies in 2004 and their cells' actual production[248] from 2001(MWp)

Ranking	***Company***	***2001***	***2002***	***2003***	***2004***
1.	Sharp (Japan)	75	123	198	324
2.	Kyocera (Japan)	54	60	72	105
3.	BP Solar (US)	54	74	70	85
4.	Mitsubishi Electric (Japan)	14	24	40	75
5.	Q-Cells (Germany)	n.a.	9	28	76
6.	Shell Solar (Germany)	39	58	73	72
7.	Sanyo (Japan)	19	35	35	65
8	Schott Solar (Germany)	23	30	42	63
9.	Isofoton (Spain)	18	27	35	53
10.	Motech (Taiwan)	n.a.	n.a.	n.a.	35

Source: Maycock (2005)

As illustrated in table 3.1, from 2001 to 2004, among the top ten global PV producers in terms of their MW production eight companies are from the countries under analysis: three from Germany (Q-Cells, Schott Solar, Shell Solar), four from Japan (Sharp, Sanyo, Kyocera, Mitsubishi Electrics), and one from the United States (BP Solar)[249]. "Given the relative size of the Japanese market, it is not surprising that four of the ten largest PV producers are Japanese firms and represent some of Japan's largest and most powerful industrial firms".[250]

In Europe, solar cells' production was led by domestic producers such as Germany's Q-Cells and Schott Solar and was also bolstered by the British BP Solar and the Dutch Shell Solar. In the United States, PV production was dominated by the divisions of these last two European oil companies', and by General Electric. The latter entered the solar market only in 2004 by

[248] Actual production is larger than installed capacity due to delays between production of the modules and their effective installation. On the other side, actual production is smaller than end-of-year production.

[249] It is the division of the British oil company BP and it is headquarterd in San Francisco, California.

[250] "These companies are dominant electronics firms with market penetration and expertise in cost reduction via large-scale production development, and they have been responsible for the reductions in system prices for these markets since 1994". T. Bradford, *Solar Revolution*, MIT Press, 2006: 105.

purchasing America's largest independent PV producer, Astropower, out of bankruptcy, and created research centers in the US and in Germany for further development of renewable-energy technologies, including solar cells. On the other hand, it is worth noting that in the mid-1990s German companies (Siemens Solar – today Shell Solar, and DASA/ASE - today Schott Solar) moved production to the United States when the first German Solar Roof Program ended in 1995 causing serious consequences for the German PV industry.

As observed, the polysilicon shortage in 2005 led to changes in the PV market structure. Tight supply of silicon feedstock caused long-term polysilicon contract prices to increase by up to 25%. According to the California-based solar consultancy Solarbuzz[251], the capacity shortfall in 2005 restricted world PV market growth to just 10% in 2006. Solar cell production reached a consolidated figure of 1,656 MW in 2005, up from 1,146 MW of the previous year. Japanese producers maintained their leadership with 46% share, while Europe accounted only for 28%. US solar cells' production was as small as 156 MW in 2005, of which BP Solar accounted for more than half of the total. Despite this new situation in the world PV market the solar cells manufacturers' ranking remained more or less the same in 2005, with the only difference that the two German companies, Q-Cells and Schott Solar, raised production and reached the third and fourth position respectively. As a result of the 2005 PV market turmoil, in 2006 new solar companies made their entry among the top PV producing companies, such as SunPower and Suntech, whereas the old top PV players became more aggressive through making significant investments in new technologies and ramping up production (Tab. 3.2).

Table 3.2 Top ten PV cell manufactures in 2006 (actual production in MWp).

Ranking	***Company***	***Technology***	***MWp***
1.	Sharp (Japan)	Crystalline/Thin film	435
2.	Q-Cells (Germany)	Crystalline/Thin film	240
3.	Kyocera (Japan)	Crystalline	180
4.	Suntech (China-US)	Crystalline/Thin film	152
5.	Sanyo Electric (Japan)	Crystalline/Thin film	121
6.	Mitsubishi Electric (Japan)	Crystalline	111
7.	Schott Solar (Germany)	Crystalline/Thin film	96
8.	Motech (Taiwan)	Crystalline	92
9.	BP Solar (US)	Crystalline	78
10.	SunPower (US)	Crystalline	63

Source: Navigant Consulting, Inc. PV Services Program (2009)

[251] http://www.redorbit.com/news/science/429386/solarbuzz_reports_world_solar_photovoltaic_market_grew_34_in_2005/

In 2007/2008, major changes in the top PV global companies' ranking occurred (Tab. 3.3). German Q-Cells became the leading solar PV producer worldwide in the end of 2007, despite the shortage of silicon, and maintained that position in 2008 thanks to its technology driven cost reduction capacity.[252] Furthermore, for the first time in 2007 a thin-film solar company, the US First Solar, appeared among the leading companies, showing that thin-film technology made its official entry into the PV market. The Chinese Suntech reached the second position with First Solar. Finally, former world leader Sharp of Japan fell to fourth place.

Table 3.3 Top ten PV global companies in 2008 and their cells' production in 2007 and 2008 (actual production in MWp).

Ranking	***Company***	***Technology***	***MWp (2007)***	***MWp (2008)***
1.	Q-Cells (Germany)	Crystalline/Thin film	389	574
2.	First Solar (USA)	Thin film (CdTe)	206	503
3.	Suntech (China-US)	Crystalline/Thin film	327	498
4.	Sharp (Japan)	Crystalline/Thin film	363	473
5.	JA Solar (China)	Crystalline	132	300
6.	Kyocera (Japan)	Crystalline	207	290
7.	Yingli Green (China)	Crystalline	150	282
8.	Motech Industries (Taiwan)	Crystalline	196	272
9.	SunPower (USA)	Crystalline	100	237
10.	Sanyo Electric (Japan)	Crystalline/Thin film	165	215

Source: EurObserv'ER (2009)

In 2009 the top PV stakeholder scenario changed and the US thin-film solar company First Solar moved to the number one position and surpassed the 1 MW threshold thanks to its low cost per watt (Tab. 3.4). Suntech followed at number two, but further behind in terms of megawatts. Q-Cells of Germany lost the first and got to the fourth position. It is worth noting that among the top ten PV companies in 2009, similarly to 2008, two were from the United States (First Solar and SunPower), only one was a European company (Q-Cells), and seven out of ten were from Asia, of which four from China (Suntech, JA Solar, Yingli Green, Trina Solar), two from Japan (Sharp, Kyocera), and one from Taiwan (Gintech).

2008 and 2009 are characterized by the growing importance of thin-film PV technology and the focus on BIPV and cost per watt as the main drivers of project return on investment. In 2008 newer companies like Suntech and First Solar appeared among the PV leading

[252] http://www.q-cells.com/medien/ir/hauptversammlung/2008/agm_2008_ceo_english.pdf. See also in Appendix A the R&D investment growth by Q-Cells.

companies because they satisfied both these requirements. Suntech was focused on BIPV and First Solar CdTe cells reached the lowest cost per watt.

Table 3.4 Top ten PV cell manufacturers in 2009 (actual production in MWp).

Ranking	***Company***	***Technology***	***MWp***
1.	First Solar (US)	Thin film (CdTe)	1,112
2.	Suntech (China-US)	Crystalline/Thin film	704
3.	Sharp (Japan)	Crystalline/Thin film	595
4.	Q-Cells (Germany)	Crystalline/Thin film	586
5.	Yingli Green (China)	Crystalline	525
6.	JA Solar (China)	Crystalline	520
7.	Kyocera (Japan)	Crystalline	400
8.	Trina Solar (China)	Crystalline	399
9.	SunPower (US)	Crystalline	397
10.	Gintech (Taiwan)	Crystalline	368

Source: EurObserv'ER (2010)

From table 3.4 we see many solar companies from emerging Asian economies among the top world PV manufacturers. This is a significant change in the PV manufacturing history that used to be dominated by solar companies from the developed nations. Solar industry is well known to be a capital- or technology-intensive sector, but on this aspect it is worth making a comparison between solar companies in developed and emerging economies. In the emerging economies of Southeast Asia, especially China and Taiwan, solar companies are at the beginning of their growth and they operate under a corporate strategy that utilizes inexpensive labor to perform tasks handled by equipment in the West.[253] For example, in Germany the technology component is essential to the performancef the developed PV industry. Thanks to its network of equipment and materials suppliers Germany is the leading industry cluster and one of the world's largest industrial PV market.

In the West the corporate strategy is radically different, and established European and US solar cells manufacturers are pursuing economies of scale in their manufacturing processes by using automated equipment to minimize labor costs and maximize quality control. These factors led most Asian solar companies to lower operating costs but also to more depressed gross margins. Therefore, as the solar industry in both developed and emerging economies grows, it is unlikely that labor-intensive manufacturing will be able to keep up with technology advances and larger factory scale.

[253] J. Berwind (2009), *Investing in Solar Stocks,* Mc Graw Hill, New York

In the next sections we will examine top solar companies in the analyzed countries, specifically: Q-Cells (Sec. 3.3.1), First Solar (Sec. 3.3.2), SunPower (Sec. 3.3.3), Suntech (Sec. 3.3.4), and Sharp (Sec. 3.3.5). Although Suntech is a Chinese company, for the purpose of this study it will be considered among the analyzed countries' manufacturers because it has both an operative headquarter in California, through its wholly-owned subsidiary company "Suntech Energy Solutions", and a center for research and development.

3.3.1 Q-Cells

Q-Cells of Germany, was founded in 1999, and began producing silicon solar cells in 2001. The German company occupies the cell and modules position in the PV supply chain. Its core business areas include development, production and sale of mono and polycrystalline silicon solar cells, as well as low concentration silicon-based PV technology. More recently, Q-Cells started developing and producing thin-film technologies.[254]

The company's strategy of offering a diverse portfolio of PV products is an important guarantee against technology risk. Q-Cells' strategy is based on cutting-edge technologies combined with the highest standard of quality and reduction of producing costs. With the aim of optimizing production and taking advantage of economies of scale, Q-Cells has several strategic partners from upstream and downstream value creation where the company has a high percentage of ownership. These partnerships enhance Q-Cells technological diversity.[255]

As part of its growth strategy the company undertook a plant and capacity expansion, including increasing wafer supply thanks to new contracts[256], entering into wafer production in 2007, and opening a new production facility in Malaysia. An analysis by EPIA shows a high level of PV attractiveness for many countries along varying degrees of country investment attractiveness. In the top cluster we can find Malaysia, and other key countries like China and India.[257] Incentive policy perspectives and other financial measures, such as investment tax allowance and capital allowance for companies are some of the reasons behind the growing interests by leading PV companies (SunPower and First Solar) to build production plants in Malaysia.[258]

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[254] Thin-film under the fixed substrate segment (glass), i.e., CSG (crystalline-silicon on glass), micromorph/tandem silicon, CIGS and CdTe technologies. The company produces also amorphous-silicon-on-plastic-foil technology (flexcell) under the flexible substrate segment.

[255] Examples of strategic partnerships in the wafer-based technology include the acquisition of *Renewable Energy Corporation* (17.18%), *EverQ, today Sovello* (33.33%), and *Solaria Corp. in USA* (31.4%). Examples in the thin-film business include *Sontor* (100%), *Calyxo* (93%), *Solibro* (100%), *VHF-Technologies* (57%), and *CGS Solar* (21.71%).

[256] E.g., the conclusion of a supply contract over several years with the Chinese LDK Solar on the delivery of solar wafers based on a volume of 43,000 tons of silicon to 2018.

[257] EPIA (2010b)

[258] Malaysia is one of the earliest country in the Asian region to have adopted a serious effort towards GHG emissions mitigating by enacting the "Environment Quality Act" way back in 1974. The Government approved the Renewable Energy Policy and Action Plan that will be implemented by the Ministry of Energy, Green

Also, Q-Cells' strategy aimed at a customer base expansion along with geographical diversification. In 2001, the year of Q-Cells' production onset, the national market share was 100% in the aftermath of the entry into force in 2000 of the German Renewable Energy Sources Law. In 2004, the feed-in law was revised and the lower tariffs made Q-Cells' domestic sales less convenient, thus they decreased to 63% in 2005, 40% in 2007, and down to 30% in 2008. As a result, Q-Cells' market structure in 2008 was based on around a third in domestic sales, another third to other EU countries[259], and the rest to Asia[260], Africa, and North America (Fig. 3.4).

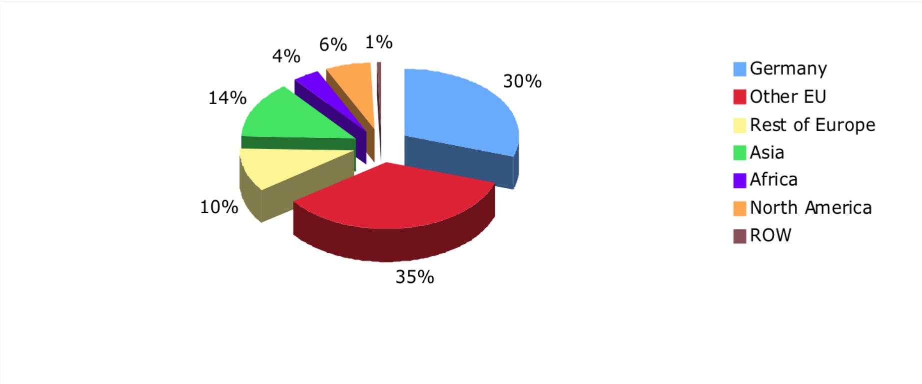
In 2009, domestic sales became predominant in Q-Cells' sales strategy and their share rose sharply up to 57% (Fig. 3.5). This was due in part to the sudden reduction of sales to Spain in the aftermath of the revision of the country's overly generous PV feed-in tariffs. Moreover, as observed, the economic turmoil transformed the solar market from a supply driven to a demand driven. Therefore, Q-Cells tended to be less aggressive in its production growth (Q-Cells' production in 2009 was characterized by only 2% growth rate from 2008 due to delayed customers' deliveries), and to concentrate more on the demand-side that is tipically driven by advantageous financial incentive measures for the production of electricity from renewable energy sources like PV, as it is the case of German feed-in tariffs.

Technology and Water in year 2011, once the institutional framework for the Renewable Energy Law and implementing agency are put in place. This new policy and the Action Plan aims not only at settling a quota system to increase PV contribution to national energy mix from currently 0.013% to 1.5% in 2010 – 2015 period, but even to establish a fixed feed-in tariff system.

[259] In 2008, the fall in the proportion of sales to the rest of Europe reflected primarily the marked reduction in deliveries to Spain and by contrast the proportion of sales attributable to Italy rose.

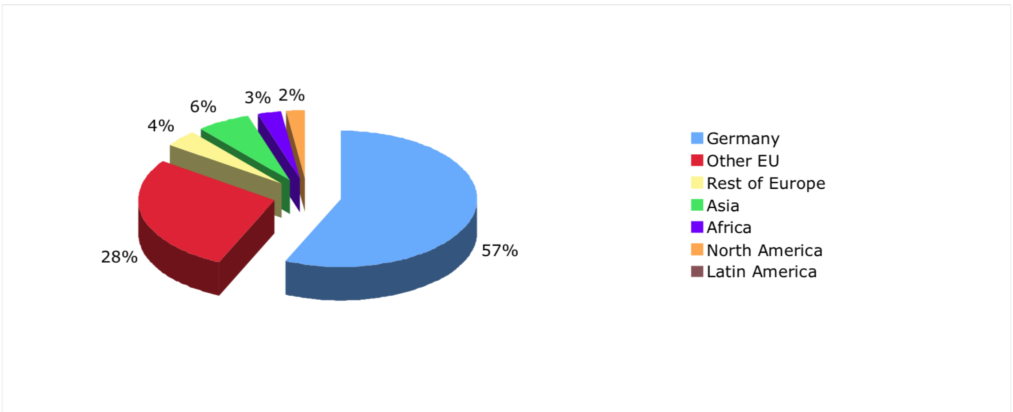
[260] South Korea and India were growing whereas Japan and Taiwan were decreasing as receiving countriesfor Q-Cells products.

Figure 3.4 Q-Cells' geographical sales distribution (2008).



Source: Q-Cells Annual Report 2009 (own calculation)

Figure 3.5 Q-Cells' geographical sales distribution (2009).



Source: Q-Cells Annual Report 2009 (own calculation)

3.3.2 First Solar

First Solar is a US company that was founded in 1999 and started its cells production in 2002. The US leading thin-film solar company is positioned in the cells and modules sector of the PV supply chain, and it is specialized in the production of thin-film modules made of cadmium telluride (CdTe).[261] First Solar is therefore largely immune to polysilicon shortages, and enjoys the lowest thin-film manufacturing cost per watt in the industry with its modules sold at $0.84/Wp in 2009.[262]

Long-term contracts for solar modules and capacity expansion are very important drivers for the growth and stability of a solar company. As of August 2008, First Solar had contracts in place to supply 3.4 GW to various customers between 2008 and 2012. As for M&A, First Solar did not have major operations before 2009, but at least a few are worth noting: the merger that took place at the beginning of 2009 with *OptiSolar,* a US manufacturer of PV modules; the acquisitions of solar project pipelines from *Edison Mission Group* in 2010; and the most recent acquisition of *Nextlight Renewable Power* in July 2010.[263] Headquartered in San Francisco, California, *NextLight Renewable Power*[264] is a leading independent solar power development company. This transaction represents a further strategic step in First Solar's expansion in the US utility-scale power market.[265]

The main target exporting countries are Germany, France, Malaysia, and China with whom a Memorandum of Understanding for a 1.3 GW utility scale project has been signed in 2009[266.] It is interesting to notice that Germany is First Solar's main target country thanks to its favorable feed-in tariff system, its market stability and the secure environment along the entire supply chain of production.

As far as domestic vs. national sales are concerned, in 2009 First Solar's thin-film CdTe modules were sold for 93% outside of the United States. Therefore, the company financial performance could be affected by events such as changes in foreign currency exchange rates,

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[261] J. Berwind, Investing in Solar Stocks: What You Need to Know to Make Money in the Global Renewable Energy Market, McGraw-Hill, 2009: 74

[262] First Solar enjoys many benefits from the manufacturing perspective. The production process is geared to high-volume, continuous manufacturing. Also, First Solar uses a "Copy Smart" methodology that allows it to rapidly replicate manufacturing facilities. The target market is mainly large and commercial-scale applications, and First Solar has introduced a customized supply system.

[263] Database Special Merger Sectors Online, consulted on March 2010 at Haas School of Business, Berkeley, CA, USA.

[264] NextLight was formed in 2007 to respond to the growing demand for clean, carbon-free, utility-scale renewable energy. For more information, visit NextLight at http://www.nextlight.com

[265] In the US, First Solar is involved in major utility-scale projects with California Investor-Owned Utilities, among which are two in operation as of March 2010 (the 10 MW El Dorado Energy Solar Project with PG&E in Nevada that is due to expand to 58 MW, and the 21 MW FSE Blythe with Southern California Edison), and many other projects under development (among which the 550 MW Topaz Solar Farm with PG&E in California, and 550 MW Desert Sunlight with both Southern California Edison and PG&E in California).

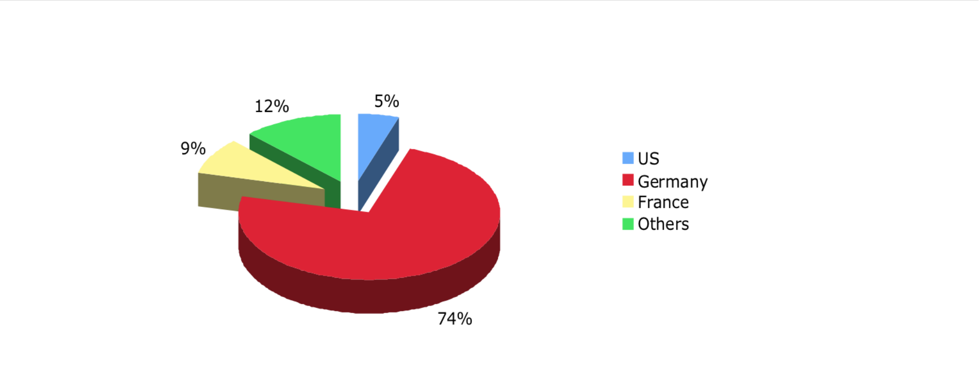
[266] Author interview with Benny Buller, Director of Device Improvement at First Solar, conducted at the US Thin Film Conference, San Francisco, December 3-4, 2009.

trade protection measures, foreign energy and technology policies, and changes in regional or worldwide economic or political conditions. Nevertheless, First Solar did only take into account a defined geographic risk because its solar modules were predominantly sold to customers for use in solar power systems concentrated in a single country, Germany. In subsidized feed-in tariff markets, such as Germany, First Solar had historically sold the most of solar modules to solar project developers, system integrators and independent power producers. In 2008 Germany accounted for 74% of total net sales, and in 2009 for 64% (Fig. 3.6 and 3.7). During the second half of 2009, German installation activity was stronger than in the first half of 2009, driven by a combination of anticipation of reduced German feed-in tariffs in 2010, seasonal demand, and also customer participation in the company's rebate program.

On the other hand, the national market accounted for just 5% in 2008 and 7% in 2009 of total First Solar's sales revenues. In markets such as the United States, the demand for PV systems is driven by renewable portfolio standard that is made of large-scale PV systems. In order to meet the needs of this market, First Solar developed a fully integrated systems business that can provide a low cost utility-scale PV system solution for system owners and low cost electricity to utility end-users.

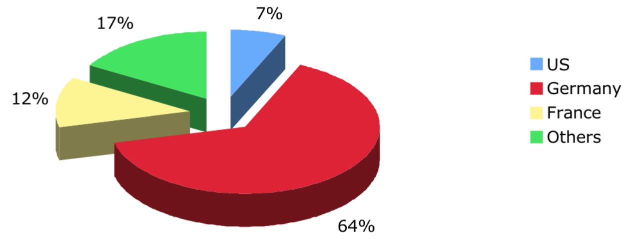
In conclusion, the concentration of sales in one geographic region exposed First Solar to local economic and public policy and regulatory risks in Germany. The growing awareness of this risk drove First Solar towards diversification of solar modules destination markets and expansion towards transitional, and eventually economically sustainable markets that are expected to develop in areas with abundant solar resources and sizable electricity demand, such as the US national market, China, India, and some other countries in Europe, such as Italy and France.

Figure 3.6 First Solar's geographical sales distribution (2008).



Source: First Solar Annual Report 2009 (own calculation)

Figure 3.7 First Solar's geographical sales distribution (2009).



Source: First Solar Annual Report 2009 (own calculation)

3.3.3 SunPower

SunPower was founded in 1985 when Dr. Swanson, a professor of electrical engineering at Stanford, had been awarded grants from the Electric Power Research Institute and the Department of Energy to support his solar power explorations. With the help of these funds, as well as financial support from venture capital firms, SunPower was officially incorporated in 1985. Its core product is monocrystalline silicon solar cells and it is a vertically integrated company serving the residential, business, and utility markets.

With the aim of enlarging its network of partnerships, in January 2007, SunPower acquired all the stocks of *PowerLight Corp*, a US manufacturer of commercial-scale solar electric products, thus capturing a huge market for high-quality commercial and industrial installations of solar PV systems.[267] A year later, SunPower acquired *Solar Solutions srl*, an Italian Faenza-based manufacturer of solar systems and in February 2010, it announced agreement on the acquisition of *SunRay Renewable Energy Ltd*, a leading European solar power plant developer based in Malta. Through this acquisition "SunPower will acquire a project pipeline of solar photovoltaic projects totaling more than 1,200 megawatts (MW) in Italy, France, Israel, Spain, the United Kingdom and Greece".[268] A SunPower-SunRay agreement was first reached in September 2009, when SunPower announced an agreement to build a 24-megawatt solar electric power plant in Montalto di Castro as the largest operating solar power plant in Italy. This agreement further accelerated the growth of SunPower European and Middle Eastern power plants business.[269]

The company's strategy of vertical integration was expected to help it combat the silicon shortage of 2005, since SunPower would be in a position to capture a larger area in the solar PV chain and have more control of the module sales distribution channel. SunPower's major

[267] It is worth noting that the installation business contributed up to 60% of the SunPower total business revenue.

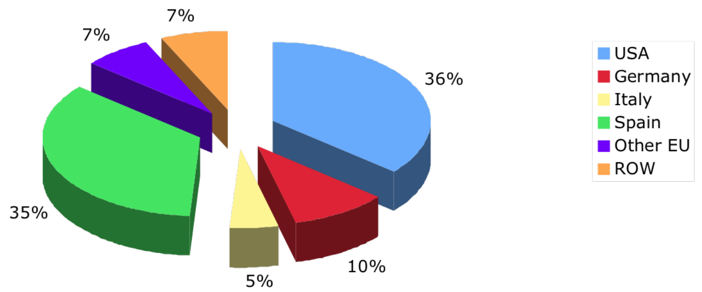
[268] http://investors.sunpowercorp.com/releasedetail.cfm?ReleaseID=444349, accessed January 2011.

[269] Source data on M&A: Merger Online, accessed on March 2010, at Haas School of Business, Berkeley.

differentiating factor is the trade-off between higher costs,[270] and higher conversion efficiency and better quality in solar cells' design. However, despite its integration strategy, a systems' price decline in the market could exercise pressure, should competing module supplies become vastly cheaper than in-house production.

In 2009 SunPower, which has its own crystalline-silicon cell and moduling manufacturing facilities in the Philippines and China, changed its strategy and aimed at centralizing the production and assembling up to a quarter of its solar panels in the United States from 2011.[271] This move was driven by the need to be closer to a growing US domestic market.[272] In 2008, domestic sales within the United States accounted for 36% but grew up to 43% in 2009. As for the exporting areas, the main receiving geographic region was Europe, especially Italy and Germany (22% and 21% in 2009 respectively). As for Spain, due to the cap to the feed-in tariffs in late 2008 the export share decreased considerably from 35% in 2008 to only 3% in 2009 (Fig. 3.8 and 3.9).

Figure 3.8 SunPower's geographical sales distribution (2008).



Source: SunPower Annual Report 2009 (own calculation)

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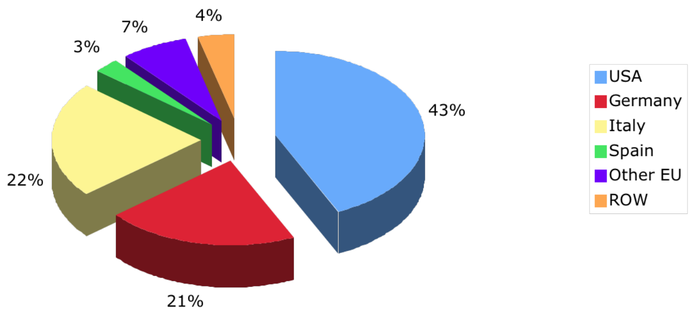
[270] The average price in $ per KW will decrease to less than $1 by 2014. (Author interview with Matt Campbell, Director, Utility Products, on November 30, 2010, at SunPower Corp, Richmond, CA, Usa.)

[271] http://www.pv-tech.org/news/_a/report_sunpower_plans_to_start_manufacturing_solar_pv_panels_in_u.s/

[272] In the United States, a project that is already operational and can be considered as the largest-operating solar photovoltaic power plant in North America under development is the 25 MW with *Florida Power & Light* in De Soto County, Florida. This same project is planned to grow to 100 MW by the end 2010. Moreover, as a long-term strategy for capacity expansion, SunPower entered into a contract with the California utility PG&E to supply 250 MW of modules.

Figure 3.9 Sun Power's geographical sales distribution (2009)



Source: SunPower Annual Report 2009 (own calculation)

3.3.4 Suntech

Suntech of China was founded in 2001 and opened its production in 2003. In the same year it opened a facility that can be considered as the first manufacturer of crystalline-silicon solar cells in China. In December 2005, Suntech was first publicly traded in the United States. Suntech core technology is crystalline-silicon cells, both mono and multi, but as a strategic move to enlarge its product portfolio it added in the pipeline the production of thin-film technologies. Suntech occupies the cells and modules position in the PV supply chain.

Instead of integrating upstream into wafers and ingots, Suntech focused mainly on the downstream side, in the form of value-added building-integrated photovoltaics (BIPV) and system integration. As part of its push into BIPV, Suntech has taken in August 2006 a strategic stake in *MSK Corp.*, a Japanese company manufacturer of photovoltaic devices that specialized in this area. In December of 2007 the operation was concluded by the acquisition of the remaining interest in *MSK Corp.*[273] This integration strategy may represent a good opportunity for Suntech if in the long run should solar PV become synonymous with building materials more generally.[274] On the upstream side, in 2008 Suntech raised its raw material supplies in a long-term strategy and it announced long-term contracts with the German *Wacker Schott Solar GmbH*, and with the British PV *Crystalox Solar*, securing the supply of wafers over a five-year period from 2008 to 2013, at fixed prices and volumes.[275]

This company used to have five manufacturing sites, of which four in China and one in Japan. In 2008, with the aim of moving production to the United States, Suntech acquired *El Solutions Inc.,* a US manufacturer of commercial and utility-scale solar power systems, from

[273] Merger Online Database, accessed March 2010 at Haas School of Business, Berkeley, USA.

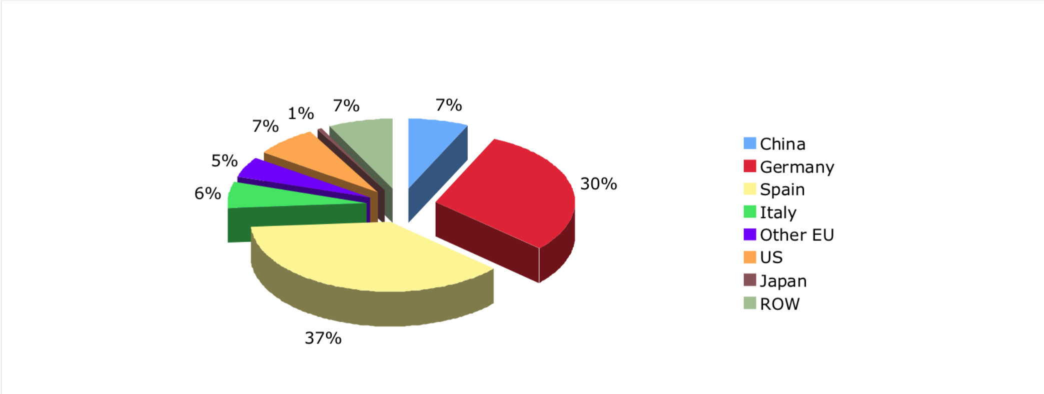
[274] Berwind, *op. cit.:* 82

[275] Author interview with Andrew Beebe, Manager Director of Suntech Energy Solutions, November 5, 2009

Energy Innovations, and named this wholly-owned company *Suntech Energy Solutions*. In 2010, a new module manufacturing plant was located in the United States at Goodyear in Arizona, to be the first Chinese company to open in the United States.

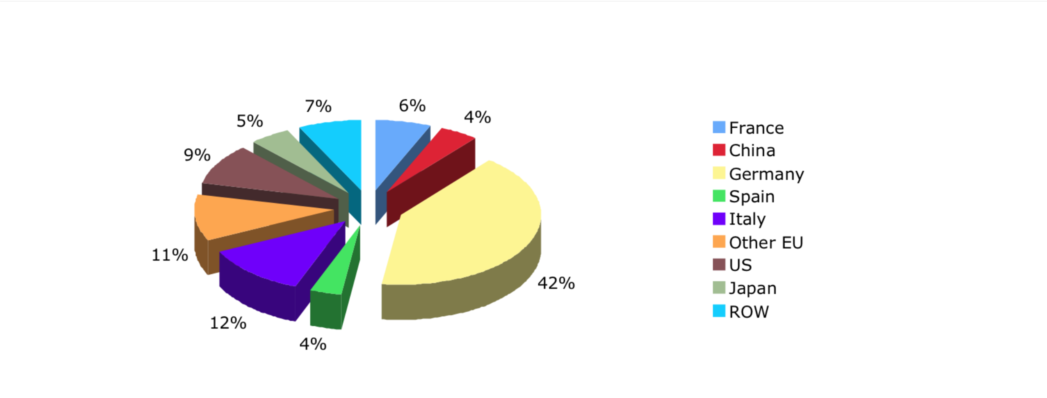
In 2009, Suntech main exporting region was Europe with 75% share, with Spain that almost disappeared from its position of main receiving country; Germany that grew from 30% to 42% of Suntech's sales; and Italy, where the exported capacity doubled from 6% to 12%. The US followed with 9% share of Suntech output, whereas Asia (mainly China, Japan) received 10% of the company production. Australia, South Africa and the Middle East are in the pipeline for new exporting countries (Fig. 3.10 and 3.11).

Figure 3.10 Suntech's geographical sales distribution (2008).



Source: Suntech Annual Report 2009 (own calculation)

Figure 3.11 Suntech geographical sales distribution (2009).



Source: Suntech Annual Report 2009 (own calculation)

3.3.5 Sharp

Sharp of Japan began developing solar cells in 1959 achieving mass production in 1963 and has since then led the solar electric industry. In 1966 the first Sharp' solar cell was installed on a lighthouse and in 1976 it was located on a Japanese satellite as a self-sustained energy source.

The portfolio of Sharp PV products ranges from mono and polycrystalline-silicon solar cells to triple-junction thin-film silicon,[276] which boasts higher conversion efficiency than conventional tandem (two layer) cells. Sharp Solar is also conducting cutting-edge research on the third generation of solar cells technology, dye-sensitized solar cells.[277] In 2002 Sharp Solar developed a technology for recycling of old PV modules and re-using the solar cell components, introducing a new important aspect in the PV production chain. These example explains how Sharp Solar aims to establish a presence across the entire value chain as total solutions provider.

It is worth noting that Sharp Corp. produces a wide variety of electronic products, including not only solar cells, but also LCDs and "other electronic components". Just to give a measure of photovoltaic as a share of total Sharp's product portfolio, in March 2009, solar cells, including silicon-based and thin-film, made 5.5% of total Sharp's annual net sales. Due to the variety of products and the difficulty of finding segmented data for solar cells, we will take into consideration the total portfolio of product for R&D intensity, whereas data on revenues for solar cells segments are available, although not specifically for country-based export share.

In 1962, Sharp expanded outside of Japan and established its subsidiary *Sharp Electronics Corp.* in the United States, the company's first overseas sales base. It is interesting to note that *Sharp Solar Energy Solutions Group*, a division of Sharp Electronics Corporation, was based in California in order to take advantage of the conducive technological and policy framework characterizing the Golden State. In 1979, the Japanese company set up the *Sharp Manufacturing Company of America* with the aim of creating a manufacturing base in the US. Furthermore, Sharp did not limit itself to sales and manufacturing in the US, and in 1995 it opened *Sharp Laboratories of America*, a US-based research and development laboratory designed to take advantage of American research and development skills.

In Europe, Sharp opened many sales and manufacturing subsidiaries, such as a European energy division in Germany, with the aim of gaining market share in Northern and Southern Europe, and a European research and development laboratory in the United Kingdom. More recently, in Italy Sharp entered an agreement with *STMicroelectronics* and *Enel* to set up a

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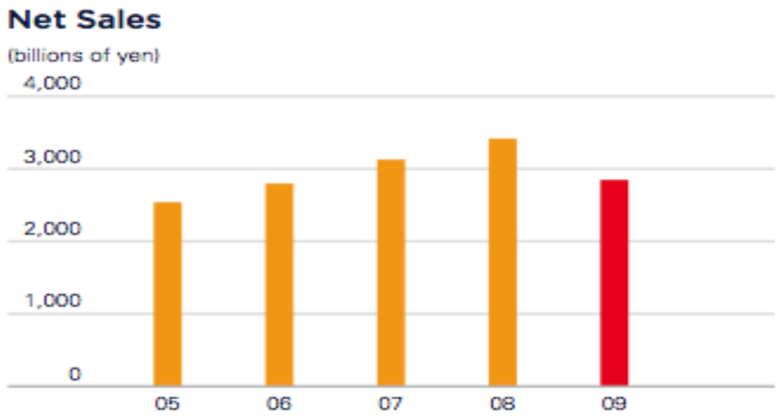
[276] This technology consists of two amorphous silicon films with a layer of microcrystalline silicon to achieve higher stability and better performance than previous thin-film solar.

[277] Thin-film is Sharp technology roadmap to achieve a lower cost per KWh. Sharp has invested $815 million in a new dedicated production plant at Sakai City near Osaka, the world's largest thin-film manufacturing complex.

joint venture to manufacture triple-junction thin-film solar cells in Catania, Sicily to be operational in the second half of 2011.

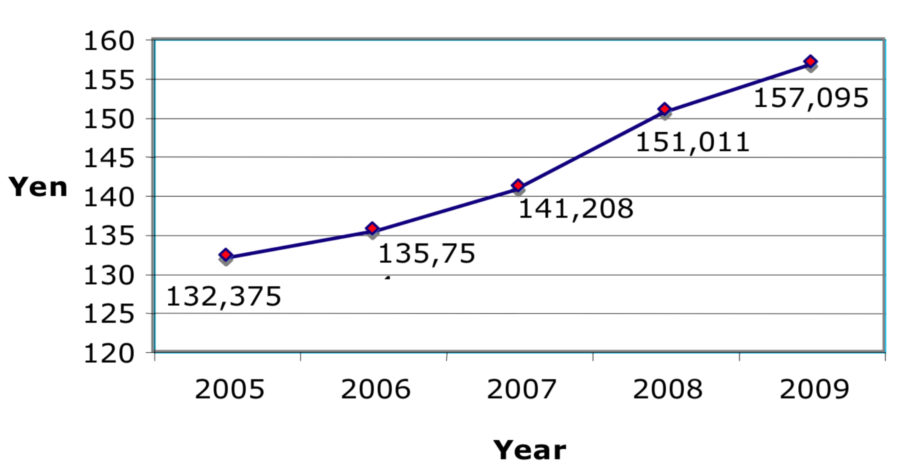
In order to understand the share and the special position of Sharp solar cells' production in its total portfolio of products, we can analyze Sharp turnover performance in 2005 and 2009. As we see in figure 3.12 total net sales gradually grow up until 2008 and in 2009 they registered a negative growth as a result of the 2008 economic turmoil. On the other hand, as we see in figure 3.13 solar cells net sales from 2005 and 2009 were steadily increasing and in 2009 the production of solar cells was characterized by a year-by-year growth of 4%.

Figure 3.12 Sharp's overall net sales (2005-2009).



Source: http://sharp-world.com/corporate/ir/library/annual/pdf/2-3.pdf

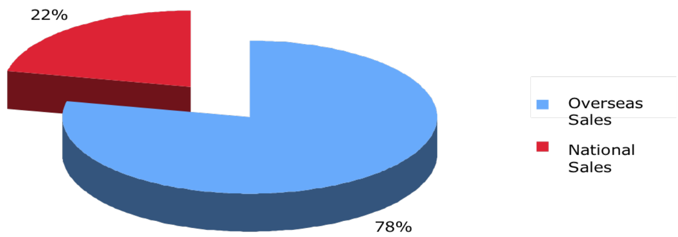
Figure 3.13 Sharp's net sales of solar cells 2005 - 2009 (in Million of Yen).



Source: Own calculation on Sharp data

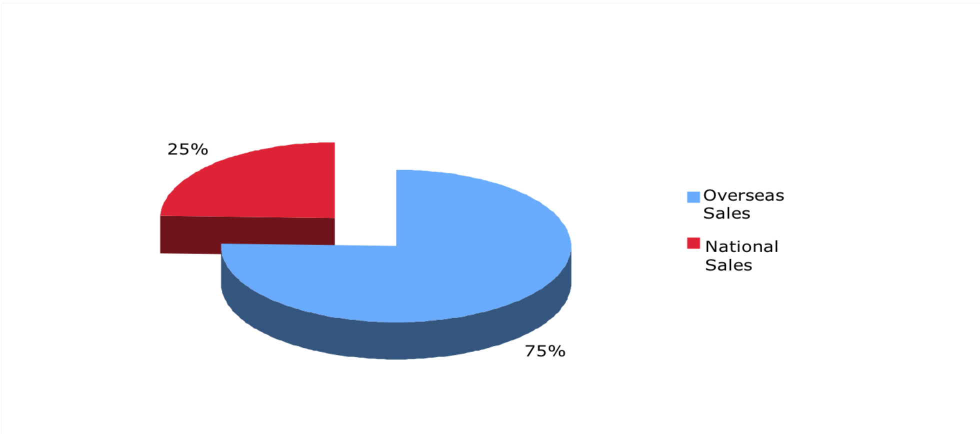
Figure 3.14 and 3.15 describe Sharp share of national net sales as compared to overseas sales of solar cells in 2008 and 2009. If in 2008 the ratio of national sales was 22%, in 2009 the ratio grew up to 25%. We can observe that Sharp strategy is definitely towards overseas sales, for two reasons, the first is that competition at home is very high, and the second is that Sharp is looking at foreign markets where energy policies for the production of electricity from solar energy are driving the installation of solar cells. As observed, more data on Sharp solar cells separated from data on the entire Sharp product portfolio importing countries are not available.

Figure 3.14 Sharp's geographical sales distribution of solar cells (2008).



Source: Sharp Corporation, Consolidated Financial Highlights (2005 – 2009)

Figure 3.15 Sharp's sales distribution of solar cells (2009).



Source: Sharp Corporation, Consolidated Financial Highlights (2005 – 2009)

3.4 Effects of Technology-Push Policies on Companies' Performance in California, Germany, and Japan

This section analyzes the performance of the national companies of the considered countries and its relationship with the evolution of technology policy instruments in California (Sec. 3.4.1), Germany (Sec. 3.4.2), and Japan (Sec. 3.4.3). Technology-push policies are divided into direct and indirect, where in the first case we consider instruments from the field of R&D policy, and in the second case we consider instruments from any policy field that indirectly impact on R&D investments. In the first category are direct government R&D funding to private firms, government laboratories and universities, and in the second category are R&D tax credits and patent protection.

We assume that R&D outputs, as measured by contributions in terms of papers presented by universities and national laboratories to major conferences, have a strong correlation with R&D budget. Therefore, we can consider the number of papers a proxy of R&D funding and conducive research infrastructure. Based on this assumption, we see from table 3.5 that the countries with the largest production of papers in the all spectrum of PV technologies and therefore with the largest PV R&D budget are Germany, Japan and the United States.

Table 3.5 Total number of papers presented at the WCPEC–4, 19th EU–PVSEC and PVSEC-17 by R&D institutions and universities.

Rank	Affiliation	Country	1	2	3	4	5	6	7	8	Total
1	Fraunhofer ISE	Germany	6	0	8	61	0	7	5	5	92
2	NREL	USA	8	13	8	6	4	7	4	5	55
3	AIST	Japan	14	7	1	6	15	4	5	1	53
4	Hahn-Meitner Univ.	Germany	3	12	1	16	5	0	1	0	38
5	UPM	Spain	9	0	10	7	0	6	2	2	36
6	Toyota Tech. Inst.	Japan	6	0	17	9	0	1	0	1	34
7	Univ. Konstanz	Germany	1	0	0	29	0	2	0	0	32
8	Tokyo Inst. Tech.	Japan	5	6	1	6	11	0	0	2	31
9	UNSW	Australia	9	0	0	12	1	2	2	4	30
10	IMEC	Belgium	3	0	2	21	0	2	0	0	28
11	Tokyo Univ. A. & T.	Japan	1	0	0	12	1	0	10	2	26
12	EC-JRC	EU	1	0	0	0	0	8	5	5	19
13	ENEA	Italy	0	5	0	6	4	3	0	0	18

The categories are: 1 = Fundamentals, Novel Materials and Devices, 2 = II-VI & CIGS, 3 = III-V, concentrator & Space, 4 = Crystalline Silicon, 5 = Thin Film Si, 6 = PV Modules and components, 7 = PV Systems, 8 = Programmess, Policies, Economics, Environment.

Source: ISPRE (2009)

3.4.1 California

We see from table 3.5 that the DOE's National Renewable Energy Laboratory (NREL) is the only US research institute and it is at the second position for the number of papers presented in the 19th EU-PVSEC, PVSEC-17, and WCPEC-4 conferences.[278] Also, it is worth noting that the NREL has been more active in PV R&D research on CIGS solar cells (13 out of a total of 55 papers).

If we analyze the history of the technology-push in the PV field in the United States, it is interesting to notice that the US led the first stage development of PV market growth in the 1970s and had one of the highest public funding to PV R&D: US PV program funding was considerably high in the 1970s, then it was sharply reduced in the 1980s, and subsequently increased in the early 1990s.[279] As reported by the Department of Energy in 2003, the government's investment in photovoltaics since 1974 was estimated to be $1.7 billion.[280] In 2000s it started rising again, especially from 2007 and it grew dramatically in the aftermath of the 2008 economic turmoil.

This was mainly the result of the US very well organized research infrastructure in the PV field, and the existence of several centers of excellence, including the DOE, its program office on Renewable Energy (EERE) and the DOE's Solar Energy Technologies Program[281], DOE's national laboratories[282], including the National Renewable Energy Laboratory (NREL) and Sandia National Laboratories (SNL), universities, private research consortia, non-profit research institutions, and individual firms (Fig. 3.16).

[278] 19th European Photovoltaic Solar Conference (EU-PVSEC), 17th International Photovoltaic Solar Energy Conference (PVSEC-17), 4th World Conference on Photovoltaic Energy Conversion (WCPEC-4).

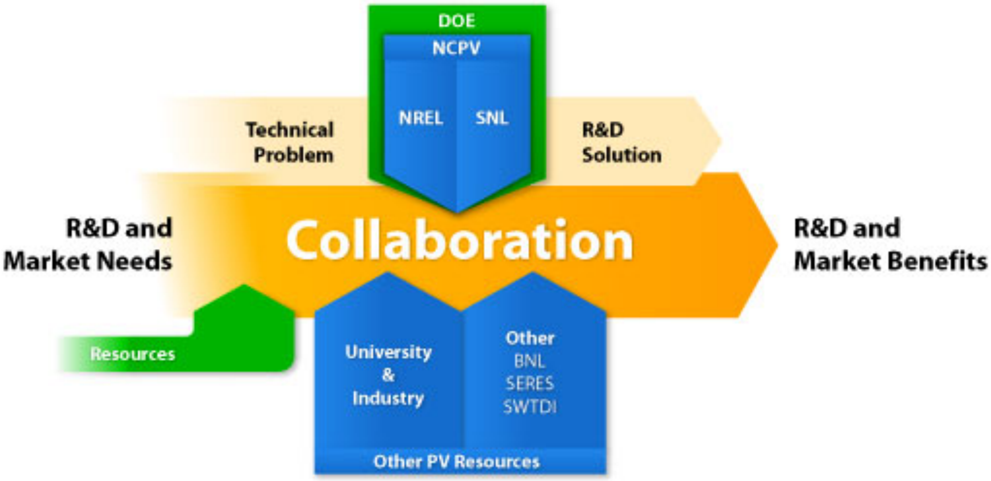
[279] As already observed in chapter 2 the government funding to PV R&D amounted to $57 million in FY 1978 and grew to $155 million in FY 1981. During the Reagan administration federal research funding to PV steadily decreased and in FY1989 they amounted to $ 35.5 million. Federal funding raised again in the 1990s and in 1992 they amounted to $114 million.

[280] A. Luque, S. Hegedus (ed.), *Handbook of Photovoltaic Science and Engineering*, John Wiley and Sons, 2003: 1097

[281] Within the DOE the Office of Science focuses on basic research, while program offices such as the EERE focus almost entirely on applied research and development. Solar Energy Technologies Program of the EERE http://www1.eere.energy.gov/solar/

[282] The US national labs are 16 and they perform about two-thirds of DOE-funded energy R&D and receive about 95% of their funding from the Federal government. The main DOE labs focused on energy science and technology are the university-administered Ames, Argonne, Fermi, and Lawrence Berkeley labs. National labs are overseen by the DOE Office of Science, except for the National Renewable Energy Laboratory which is overseen by the Department EERE Program office.

Figure 3.16: Photovoltaic research and development system in the United States.



Source: National Renewable Energy Laboratory (http://www.nrel.gov/pv/ncpv.html)

Notes:

NCPV: National Center for Photovoltaics now part of the DOE Solar Energy Technologies Program

BNL: Brookhaven National Laboratory

SERES: Southeast Regional Experiment Station

SWTDI: Southwest Technology Development Institute

While government funding is essential in supporting demonstration and early-deployment stages of technology innovation to help technologies across the "valley of death"[283], evidence of private sector investment is an important indicator of expectations about technological possibilities and market potential. Therefore, private sector investment activity is a key area of concern. Yet, private investment by large US companies in developing renewable and PV technologies has actually declined, falling by 50% between 1991 and 2003. However, industry plays a very important role in funding university research. As an example, in 2007

[283] The "valley of death" of technologies occurs when newly developed technologies fail from crossing the early adopters' phase of the technology adoption lifecycle. The "valley of death" coincides in time with the transition from publicly to privately financed operations, meaning the transition from government RD&D funding and supported commercial technologies involving private investors. This transition to private sector financing is made difficult since the availability of public sector funds decreases abruptly after the technology is created.This is because the public sector views subsequent investment and further progress towards commercialization as the purview of the private sector.

industry contributed to 5.4% of all R&D expenditure ($49.4 billion) by departments of science and schools of engineering at US universities and colleges.[284]

Especially in the PV industry, a combination of public and private RD&D funding along the entire innovation chain is pivotal. In the United States, government funding to RD&D is still the most common direct technology-push policy that has enabled PV companies to develop new technologies and pursue additional research opportunities whilst helping to offset their private R&D expenses.

A direct technology-push policy for the growth of PV industry is the federal government R&D funding to universities and colleges. "The US federal government remains the largest source of academic R&D funding, accounting for more than 60% of total R&D expenditure most years since 1972".[285] Of the 673 US universities and colleges offering degrees in the sciences or engineering surveyed by the National Science Foundation (NSF) in 2008, among the top 100 research performers in terms of total federally financed R&D expenditure, 8 are California-based universities.[286] In the field of engineering these top private and public universities in California received more than $400 million from federal funding in 2008.[287] Considering that the total federal funding to schools of engineering at US universities and colleges in 2008 was $4.7 billion in 2008, the R&D funding to the top California's engineering schools was 8.5%. E.g., the University of California, Berkeley, received $48 million from federal funding in the field of engineering, around one fifth of the total $249 million of federal R&D expenditure in all fields in 2008.[288]

Moreover, it is worth noting that the NSF survey does not include R&D performed by university-administered federally funded research and development centers. For example, the Lawrence Berkeley National Laboratory (LBNL), as observed above (Sec. 1.2.4), where different research groups work on PV innovative solar cells and especially within the third generation solar cells and new materials[289], is not included in the funding received by the University of California Berkeley. Although LBNL is university-administered, it does receive separate funding from the federal US government for PV R&D.[290] Other University of California-administered national labs are the Lawrence Livermore National Laboratory, and

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[284] R. Britt, "Universities Report Continued Decline in Real Federal S&E R&D Funding in FY 2007", NSF 08-320, August 2008. http://www.nsf.gov/statistics/infbrief/nsf08320/nsf08320.pdf

[285] R. Britt, *op. cit.*: 1

[286] Stanford University, UC Los Angeles, UC Berkeley, UC Davis, UC San Diego, UC Irvine, UC Santa Barbara, UC Santa Cruz, California Institute of Technology.

[287] Excluding R&D performed by university-administered federally funded research and development centers.

[288] National Science Foundation/Division of Science Resources Statistics, Survey of Research and Development Expenditures at Universities and Colleges, FY 2008.

[289] *E.g.,* the "Helios Project" founded by Steven Chu in 2005 http://www.lbl.gov/LBL-Programs/sp_energy.html

[290] Berkeley Lab's Computational Research Division received $4.0 million as ARRA funds for six projects that will help to answer some of the nation's most pressing questions regarding energy and next-generation, of which three address PV solar energy. E.g.: enhancing Productivity of Materials Discovery Computations for Solar Fuels and Next Generation Photovoltaics, $200,000; Large-Scale Eigenvalue Calculations in the Study of Electron Excitation for Photovoltaic Materials, $702,000.

Los Alamos National Laboratory that is located in New Mexico but since 1943 is UC-administered on behalf of the federal government.

In sum, California is the US state that receives the largest amount of both federal and private funding to academic R&D. In the 5-year period 2003-2008, California colleges and universities received 13.3% of federal funding ($23 billion)[291], and 12.7% of industry funding ($1.8 billion).[292]

Also, PV companies in California are very good at being awarded federal R&D grants for research in the PV field. For instance, DOE's National Renewable Energy Laboratory (NREL) has announced on January 2010 to invest up to $12 million in total funding, including $10 million from the 2009 American Recovery and Reinvestment Act (ARRA), in four companies to support the development of early stage solar energy technologies to full commercial scale. The awards are part of NREL's PV Incubator Program and three out of four project awardees are start-up companies from California.[293]

3.4.1.1 A California's case study: SunPower

We take SunPower as a case study for California's PV company, because it is not only one of the top PV companies worldwide but also because it is the company that better explains the effects of direct and undirect technology-push policies and of industry-academia collaboration. This important collaboration is very well explained by SunPower founding history that traces back to 1985 when SunPower' co-founder Swanson decided to commercialize concentrating photovoltaic technology originally developed while he was a Professor at Stanford University in California.[294] SunPower was incorporated in 1985 after having been awarded grants from the Electric Power Research Institute and the Department of Energy, as well as financial support from two venture capital firms, to contribute to his solar power explorations.

We will analyze both direct and indirect technology-push policies effects on the performance of SunPower. As for direct R&D government subsidies, they have offset SunPower R&D expenses by approximately 22%, 25%, 21%, 8% and 7% in fiscal years 2009, 2008, 2007, 2006 and 2005, respectively. From these data we can see that government R&D funding to SunPower have dramatically increased from 2005 to 2009, thus creating a positive effect in

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[291] http://www.nsf.gov/statistics/nsf10311/pdf/tab20.pdf

[292] http://www.nsf.gov/statistics/nsf10311/pdf/tab22.pdf

[293] *Alta Devices, Inc.* (Santa Clara, California): project on the development of a high-efficiency (>20%), low-cost compound-semiconductor PV module; *Solar Junction Corporation* (San Jose, California): project on the development of a manufacturing process to produce a very high efficiency multi-junction cell; *Tetra Sun* (Saratoga, California): project on the advancement in back surface passivation for high efficiency crystalline silicon solar cells. For more details about the awards: http://www.nrel.gov/news/press/2010/802.html

[294] Dr Swanson is co-founder of SunPower Corp., and since 2003 President and Chief Technical Officer. While Swanson was making his first foray into the solar arena in Palo Alto, some other pioneers across the San Francisco Bay in Berkeley were charting a similar corse. PowerLight was founded in Berkeley and in 2007 it was acquired by SunPower.

stimulating in-house R&D investments and consequent patent production.[295] Just to give an example, in 2007 SunPower signed a Solar America Initiative R&D agreement with the US Department of Energy in which it was awarded $18 million as of January 2010. Total DOE funding to SunPower for the three-year R&D effort was estimated to be $24 million.[296]

As for indirect technology-push in the form of federal tax credits, including both R&D and investment tax credit, SunPower received from the US government $3.3 million of tax credits in 2007, $9.5 million in 2008, and $5.2 million in 2010.[297] SunPower's R&D expenditure was $13.6 million in 2007, $21.5 million in 2008, and $31.6 million in 2009.[298] As for the R&D intensity, for the same years SunPower invested 1.7% in R&D expenses as a percentage of revenue in 2007, and 1.5% in 2008 (Appendix A). If we compare data, we can observe that growing R&D expenditure by SunPower has been stimulated by important tax credit measures practiced by the US government at least until 2009.

In the legislation governing R&D tax credits in the United States, as observed above (Sec. 2.2.1.1), the US Internal Revenue Code (IRC) provides a 20% tax credit applying to payments made from corporations to qualified institutions to conduct R&D, thus including universities. SunPower holds different cooperation agreements with universities for the demonstration of SunPower' better efficiency of its solar panels compared to other competitor's panels in terms of their annual energy yield considering different climatic conditions. This is conducted through studies agreements with the universities of Loughborough in the UK, Stuttgart in Germany, as well as Arizona State in the US that have hailed SunPower as being the best for their respective climates.

Also, legislation governing R&D tax credits in the United States provides for deduction of R&D in the experimental or laboratory sense, including the cost of obtaining a patent. SunPower holds a total of more than 120 patents as of January 2010, of which 65 patents in the United States and 63 patents in foreign jurisdictions.[299] This is a very high number and, considering that SunPower enjoys of R&D tax credits for filing its patents, it is significant for assessing the impact that an indirect technology policy has on the company's performance.

In conclusion, US direct and indirect technology-push policies have together driven the growth of SunPower as one of the top global leading companies, enjoying the best panels' efficiency. Its onset in California is the demonstration of the positive impact that a very well developed research infrastructure, made of leading universities, advanced research centers, start-up companies and venture capitalists, play on the performance of a PV manufacturer.

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[295] SunPower ratio of patent families per invested R&D budget is one every € 0.6 - 0.8 million (approx. $0.87 million) of R&D investments.

[296] This contract replaced SunPower three-year cost-sharing research and development project with the National Renewable Energy Laboratory, entered into in March 2005, to fund up to $3 million or half of the project costs to design SunPower next generation solar panels. SunPower Annual Report 2009.

[297] SunPower Annual Report 2009

[298] Thomson Reuters Datastream, London.

[299] SunPower Annual Report 2009. According to the United States Patent and Trademark Office Database, SunPower was assigned 40 patents. http://www.uspto.gov/

3.4.2 Germany

We can see from table 3.5 that the Fraunhofer-ISE Institute is the one who presented the highest number of papers at the investigated conferences, and the cumulative papers' production by German research institutions and universities was the highest among all investigated countries. In particular, German research papers were mainly focused on crystalline-silicon solar cells: e.g.: Fraunhofer-ISE presented 61 out of 92 total papers on this specific PV technology, and University of Konstanz produced 29 out of 32 papers on c-Si.

Research on environmental technologies has been a priority since the 1970s, when the government launched a large number of individual programs on developing renewable technologies. In the 1970s and 1980s the attention was focused on nuclear power research, and it is only since the 1990s that renewable energies and especially PV technologies have become the focus of German technology policy. In the period 1990-2002 the average renewable R&D budget allocated to PV in Germany was equivalent to almost 60% of total budget to renewables. Nevertheless, it is from the mid-2000s that German PV budget increased faster than any other and Germany became the main contributor to PV's third stage development.[300]

Germany has created an environment in which all operators from the entire PV value chain are in close proximity to other industry, suppliers, investors, academic institutions, and research centers. Moreover, Germany promoted direct R&D through the implementation of thematic technology programs, such as the "High-Tech Strategy" launched by the Federal government in 2006.[301] The demonstration that an emphasis was laid on the link between research results and market output was given by the "New Innovation Alliance Photovoltaic", which foresees up to approx. $140 million invested in PV research by the Federal Ministry of Education and Research over the period 2011 - 2014.

The German government policy has played a central role in the success of its solar power industry, and it has helped keep science and industry pulling in the same direction with regular increases in R&D funding. The German Environment Ministry (BMU) set aside around $60 million in 2008 to support joint science-industry cooperation projects.

In order to understand the successful story of the German solar industry today, it is worth quoting the head of Fraunhofer-ISE, Weber: "The fast growth of the photovoltaic market and the industry in Germany has been an important catalyst for solar power research".[302] Indeed,

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[300] It is indicative to notice the government expenditure on R&D to Fraunhofer Society (all Fraunhofer Institutes are included) increased from 1999 when it amounted to €234 million to 2005 when it reached €441 millions.

[301] For the first time a comprehensive national strategy for all its ministries had been developed and all political sectors affecting R&D were focused technology innovation in 17 cutting-edge fields, among which energy technologies took the lead with approx. $1.4 billion. C. Rammer (2007), "Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments. The POLICY MIX" project, Country Review Germany", United Nations University and Universiteit Maastricht: 10; Germany Trade & Invest, "The Photovoltaic Industry in Germany", issue 2010/2011

[302] http://www.gtai.com/

German public research institutes receive a considerable share of their funding from photovoltaic producers. At the Fraunhofer-ISE for example about 40% of its funding is derived from industrial projects.

Also, more than 240 university degrees with strong focus on PV are offered in Germany, and one out of 10 engineering graduates works in the renewable field.[303] If a dense network of outstanding R&D institutes and universities creates ideal conditions for companies to advance their technologies and production processes, it is also true that the financial involvement of companies has been an essential criterion when selecting PV R&D projects. Research projects conducted by German companies receive between 25% and 50% funding, which helps to encourage a high level of private investment in the form of in-house R&D that is one of the highest in the photovoltaic industry worldwide. According to BSW-Solar surveys, investment in R&D from both PV suppliers (machine manufacturers) and PV industry rose from almost $8.5 million in 2002 to around $240 million in 2008.[304]

Furthermore, Germany offers a competitive tax system providing attractive tax rates for companies. In 2001, the German government implemented a comprehensive reform of the tax system to make the country a more attractive business location. On average, corporate companies face an overall tax burden of less than 30%.[305] This makes Germany’s corporate tax system one of the most competitive in Europe, allowing PV German companies to get bigger profits and thus making higher investments in research and development.

Nevertheless, the tax reform still does not address direct tax relief on R&D and innovation expenditure. The introduction of a R&D tax credit, which is well known in other EU Member States, in Japan and in the US, is not in sight in Germany. However, the innovation financing programs (e.g. personnel subsidies in the Eastern Länder) probably have a similar impact on the cash flow available to R&D as a tax credit. In fact, in Eastern Germany, investment grants are complemented by an investment allowance, which is usually allotted in the form of a tax credit.

3.4.2.1 A German case study: Q-Cells

In order to analyze the impact that German technology policy had on its national companies’ performance we take Q-Cells as our case study because it was the world leading PV company for two years, in 2007 and 2008, and it is now among the top 5 manufacturing companies for

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[303] According to OECD statistics, Germany has one of the highest rates of graduates with a doctoral degree. With 315 Ph.D. graduates per million inhabitants, Germany ranks second among OECD countries.

[304] BSW-Solar (German Solar Industry Association), “Statistics data on the German photovoltaic industry, June 2010. It is worth mentioning the role of German mechanical engineering sector since half of the PV machine manufacturers used worldwide are produced in Germany. For instance, in 2008 the sales in the German photovoltaic industry were so divided: $14 billion in the silicon, wafer, cells and modules industry, and $3.5 billion in the PV-suppliers where the export quota was 48% for the first and 68% for the last.

[305] Moreover, the German tax system allows for differing tax rates in German municipalities, and in some of those significantly lower tax rates up to 8% less are available. The overall tax burden can therefore be as low as 22.8%.

PV capacity. We will analyze both direct and indirect technology-push policies effects on the performance of Q-Cells.

As for direct technology-push measures, we compare R&D government subsidies with R&D expenditure by Q-Cells from 2007 to 2009. In 2007, Q-Cells received $1.4 million and invested $15.6 million; in 2008, it received $3.8 million in 2008 and invested $37 million; and in 2009, Q-Cells received $2.5 million in 2009 as R&D government subsidies and invested less than $30 million in R&D expenditure. From these data we can make the following observations: first, from 2007 to 2008, when Q-Cells was the top leading PV company in the world, R&D expenditure grew considerably and were sustained by a growing R&D government subsidies. Second, in 2009 Q-Cells' R&D investment decreased and this was a combined effect of decreasing R&D government subsidies and a negative Ebitda margin due to cut in sales and production forecast (Appendix B). This trend in the German technology-push policies is confirmed by investment subsidies, not specifically directed to R&D, of which Q-Cells received $1.8 million in 2003, as much as $12.5 million in 2008 (CAGR 2003-2008 39.7%.), and only approx. $1 million of investment subsidies in 2009.

In sum, since its onset in-house investment in R&D was a central focus by Q-Cells. As for R&D intensity in the same years, it was increasing from 0.95% in 2003, to 1.25% in 2007, and to 2.13% in 2008 (Appendix A). As a last note, in 2009 R&D intensity actually went up to 2.48% despite decreased R&D and investment subsidies, which showed that the company saw it critical to invest in research even, or especially, in the middle of a global economic and financial crisis

As for indirect technology-push measures, we notice that in the period from 2003 to 2005 Q-Cells received R&D personnel expense grants ranging from approx. $0.3 million in 2003 to $0.6 million in 2005. These incentives played an important role in reducing the operating costs of R&D projects in the first years of its PV production. It is important to notice that Q-Cells received these grants thanks to its favorable headquarter position in the Eastern Länder of Saxony Anhalt where the R&D tax credits system is more advanced.

Q-Cells is also very strong in the cooperation with academia (e.g., joint programs with the Martin-Luther-University and the University of Konstanz), and research centers (e.g., the Fraunhofer-ISE and the Institute for Solar Energy Research Hameln - ISFH), with the aim of finding innovative solutions and improving the quality of its products whilst driving down production costs.

As already observed, as of the first half of 2010 Q-Cells held 19 families of PV patent applications (those related to one common parent application). A lower number if we compare them to the number of PV patents held by the the Fraunhofer Institute, that amounted to 26 under the European Patent Office, 18 under the United States Patent and Trademark Office, and approximately 35 under the Patent Cooperation Treaty.[306] And also a very low number if we consider it in the framework of the whole PV patents registered in Germany. This was

[306] German Patents and Trademark Office (Deutsches Patent und Markenamt). http://www.tangible-ip.com/2010/photovoltaic-solar-cells-patents-in-europe.htm

over 250 solar PV patents registered in Germany between 2004 and 2007, and 140 more PV patents were registered in the only 2008.[307]

In conclusion, close cooperation between universities, research institutes, manufacturers, and suppliers contributed to Q-Cells development of new technologies and products and to bring them to market quickly. Although German contribution to PV occurred only in the third stage PV development, German photovoltaic industry is today at the forefront of PV technology innovation and Q-Cells continuous search for innovative solutions and better efficiency makes it one of the top world PV leading companies.[308]

3.4.3 Japan

We can see from table 3.5 that Japanese research institutions and universities are at the second position as for cumulative number of papers presented in the considered PV international conferences. PV R&D in Japan focused mainly on thin-film technology, although its crystalline-silicon module production is one of the largest in the world. Advanced Industrial Science and Technology (AIST) presented 15 papers, and the Tokyo Institute of Technology[309] presented 11 papers related to thin-film solar cells. Other Japanese universities like the Tokyo University A&T and the Toyota Technological Institute presented papers on silicon-based PV and on concentrator and space PV applications.

Although support to R&D in photovoltaics was introduced by the Sunshine Project already in 1974, Japan only contributed to the second stage development of PV market growth due to a considerable increase of PV R&D budget in the 1980s and 1990s. Government R&D expenditure in the photovoltaic field has been reported at $6 billion all along the 1980s and 1990s.[310]

The Japanese government financed R&D in the PV field both through funding to industry and support to universities and national research centers. Japan's PV technology is an exceptional example of achieving comparative advantage in the renewable energy field. Although PV R&D budget had decreased in recent years, Japan took a leading role in world PV development. In 2000 total Japanese PV effort, including subsidies, was approximately six times the R&D portion of the budget. This is due to two main factors that characterize PV technology and that Japan was able to take advantage from. First, PV technology maximizes

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[307] GTAI (2009). "The Photovoltaic Industry in Germany".

[308] http://www.gtai.com/homepage/industries/renewable-energies-resources/pv-industry/

[309] It is worth citing the Industry Liaison Membership System that the Tokyo Institute of Technology has established to promote industry-academia liaison activities.

[310] In 1981, MITI's financial support to all PV R&D was reported at 61.4 billion yen (approx. $0.25 billion) This amount increased by around a third and in 1985 it amounted to 83.6 billion yen (approx. $0.35 billion). Between 1985 and 1992 the government funding to PV diminished progressively till 1993, the year of the launch of the new Sunshine Program, when the total government support to PV grew and was reported at 66.7 billion yen (approx. $0.28 billion). The values in yen are indicated at 1985 fixed prices. Therefore, the exchange rate is calculated according to the average value of the yen to $ in 1985, that is yen 239 = US$ 1.

the benefits of learning effects because it is at the crossroad of a web of related technologies. Second, the interdisciplinary nature of its development also maximizes the benefits of technology spillovers.[311]

In conclusion, the Ministry of International Trade and Industry (MITI) played a very important role in making the Japanese companies leaders in the world PV market by encouraging cross-sector industry involvement, stimulating inter-technology and cross-sector technology spillovers, and above all by inducing industry investment in PV R&D.

3.4.3.1 A Japanese case study: Sharp

In order to analyze the impact that Japanese technology policy had on its national companies' performance, we take Sharp as our case study. Sharp advances a fundamental R&D policy of "selection and concentration", which means conducting R&D to strengthen core businesses, solar cells, and also focusing on connected themes that are expected to translate into future business pillars, such as electric cars and solar cells with incorporated leds. This is conducted thanks to an efficient R&D structure made of industry-academia-government collaboration.

We will analyze both direct and indirect technology-push policies effects on the performance of Sharp. As for direct government support in terms of PV R&D to Sharp as opposed to its in-house PV R&D expenditure, we take into consideration the period from 1981 to 1995. The reason behind the choice of this time frame is that those years were the most significant for PV development in Japan, and Sharp have a long-standing history of R&D in the solar cells since 50 years. In particular, we take years 1981, 1985 and 1993 as our reference years.[312]

In 1981, MITI's R&D subsidies to Sharp was one of the highest among Japanese PV companies, 5.9 billion yen ($25 million) as opposed to Sharp R&D expenditure of 14.5 billion yen ($61 million). In 1985, MITI's financial support decreased to 2.2 billion yen ($9 million) and Sharp R&D expenditure remained stable compared to previous years, 8.3 billion yen ($35 million). In 1993, the government financial support grew to 4.2 billion yen ($18 million), the highest MITI's contribution to Sharp since 1982 due to the adoption of the new Sunshine Program in the same year. As a result, Sharp R&D expenditure grew up again at 8.5 billion yen ($36 million).[313] We can make the following observations: in 1981 government R&D subsidies to Sharp were conducive to its higher in-house R&D expenses, in 1985 the sustained R&D in house investment was not correlated to a substantive R&D subsidies, and finally in 1993 the new Sunshine Program funding for PV R&D was an important stimulus

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[311] C. Watanabe, C. Griffy-Brown, "Inter-firm technology spillover and creation of a "Vicious Cycle" between R&D, market growth and price reduction: the case of photovoltaic power generation (PV) development in Japan", Paper presented at the International Workshop on Induced Technological Change and the Environment, Austria, 1999

[312] In 1981, the share of funding received by Sharp was almost 10% of the total Japanese R&D funding, in 1985 it was only 2.6%, and in 1993, it grew again to 6.3%.

[313] Watanabe *et al.*, "Industrial dynamism and the creation of a virtuous cycle between R&D, Market growth and price reduction. The case of photovoltaic Power generation (PV) developemnet in japan", *Technovation,* 20 (2002): 302.

for the growth of Sharp R&D expenses. This growth did not last long and the following year the R&D expenses decreased again. Sharp was good in getting MIT R&D subsidies, but other companies such as Sanyo, Hitachi, Kyocera and Kaneka championed in the funding race.

As for indirect technology-push policy, unlike Germany and the United States, in Japan there is no location restriction on where the qualified activity occurs and R&D conducted by domestic Japanese firms can enjoy 6% credit for cooperation with foreign research laboratories. Moreover, additional R&D tax credit is applicable for a company conducting R&D jointly with a qualified R&D institution at home (e.g., designated universities). For example, it is worth mentioning Sharp R&D activity into organic electronic devices at Todai-Sharp Laboratories established at the University of Tokyo in 2005[314], and joint research efforts with the Tokai University research on solar car development.[315]

Also, under corporate income tax legislation expenses incurred abroad are also treated as eligible expenses. Sharp has two R&D subsidiaries abroad: Sharp Laboratories of America in the United States and Sharp Laboratories of Europe in the United Kingdom, and therefore R&D expenses incurred in the US and in the UK are also subject to R&D tax credits in Japan. The same reasoning can be made for production tax credits, so Sharp is allowed to receive those credits for its production activity abroad. For example, in 2009 Sharp received tax credits for its production in the United States, in particular for Sharp Manufacturing Company of America facility in Tennessee.

As for patent application, Sharp has been conducting continuous solar cells' patent activities since the early 1990s. Today, Sharp is one of the top world PV patent assignee and in the silicon solar cell technology it holds a total of 126 PV patents, of which 104 in Japan, 12 in the US, and seven in Europe.[316]. As we assumed, patents can be used as long-term indicator for analyzing R&D activities. However, different companies patent protection strategies as well as a different patent protection policy might significantly influence the respective number of patent applications.

In conclusion, Japan contributed to the second stage development of PV market growth due to a considerable increase of PV R&D budget that favored Japanese firms, and among those Sharp Corporation. Its strong collaboration with universities and research centers, its flourishing patenting activity, and its 50 years experience in the solar cell production made of Sharp one of the world's leader both in terms of production volume and in terms of technology innovation in cutting-edge solar cells and in new frontiers of PV applications.

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[314] The Nanoelectronics Collaborative Research Center (NCRC) under the Institute for Industrial Science at the University of Tokyo and Sharp Corporation have jointly established Todai-Sharp Laboratories, a research base aimed at conducting research and development for flexible electronics, which is expected to be the next generation in electronics technologies. Full-fledged research activities are slated to begin December 2005. This R&D facility will operate under a multi-year (five years) collaborative research agreement signed between the University of Tokyo, a national public university and Sharp. Sharp Annual Report 2007, "No Boundaries": 26.

[315] http://sharp-world.com/corporate/ir/intellectual/popup05.html

[316] Solar & Energy Co. Ltd (2010). "Crystalline Si Solar Cell and PV Module Key Patent Analysis", Korea

3.5 Effects of Market-Pull Policies on Companies' Performance in California, Germany, and Japan

This section analyzes first the annual installed capacity data in the investigated countries in the period from 2000 to 2009 (Tab. 3.6). Afterwards, it investigates country-by-country the leading national companies' performance in terms of MW of solar panels installed, and its relationship with the evolution of market policy instruments in California (Sec. 3.5.1), Germany (Sec. 3.5.2), and Japan (Sec. 3.5.3).

This analysis entails the study on how many MW have been produced by national companies (we consider only the MW produced by top PV manufacturers as described in tables 3.2 to 3.4) in the period from 2000 to 2009 out of the whole MW installed in California, Germany and Japan (Tab. 3.6). On this purpose we make two assumptions. First, the quantity of MW installed in a specific country is the result of national market policy instruments and financial incentives for the installation of PV panels. Second, market-pull policies have an impact on the performance of national companies, in terms of production rate, and also on the performance of companies other than national companies.

Table 3.6 Annual PV installed capacity (MWp) in Germany, Japan and California

Country /Year	*2000*	*2001*	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
Germany	40*	78	80	150	600	850	850	1,271	1,809	3,806
Japan	112	135	185	223	272	290	287	210	230	484
California (US)	2** (22 US)	8 (29 US)	18 (44 US)	32 (63 US)	44 (90 US)	55 (114 US)	70 (145 US)	95 (207 US)	179 (342 (US)	220 (477 US)***

Source: EPIA (2010a), SEIA (2010); for California data from 2000 to 2004 data see Wiser *et al.*, LBNL-59282 NREL/TP-620-39300.

Notes:

* In Germany in the period from 1991 to 1999 the cumulated PV installed capacity was 57 MW.

** The US figure includes MW installed in California. From 1981 to 1998, California had a total of 6,263 kW of cumulated installed capacity.

*** This figure is 441 MW according to SEIA (2010) (www.seia.org).

Table 3.7 Installed capacity annual growth rate in Germany, Japan and California.

Country/Year	***2001***	***2002***	***2003***	***2004***	***2005***	***2006***	***2007***	***2008***	***2009***
Germany	95%	2.5%	87.5%	300%	42%	0%	49.5%	42.3%	110%
Japan	20.5%	37%	20.5%	22%	6.6%	-1%	-27%	9.5%	110%
California	300%	125%	78%	37.5%	25%	27.3%	36%	88.5%	23%

Source: Own calculation on table 3.6

The average annual growth rate of PV installed capacity over the period 1998-2002 in the United States was 21%, a far less brilliant growth compared to Germany and Japan where the average annual growth rate over the considered period was 48% and 52%, respectively.

As we see from table 3.7, the German market showed a steady growth between 2003 and 2004 with an annual growth rate of 300% that was followed by a gradual growth or even lack of growth through 2008. German PV installation registered, similarly to Japan, a 110% annual growth rate from 2008 to 2009.

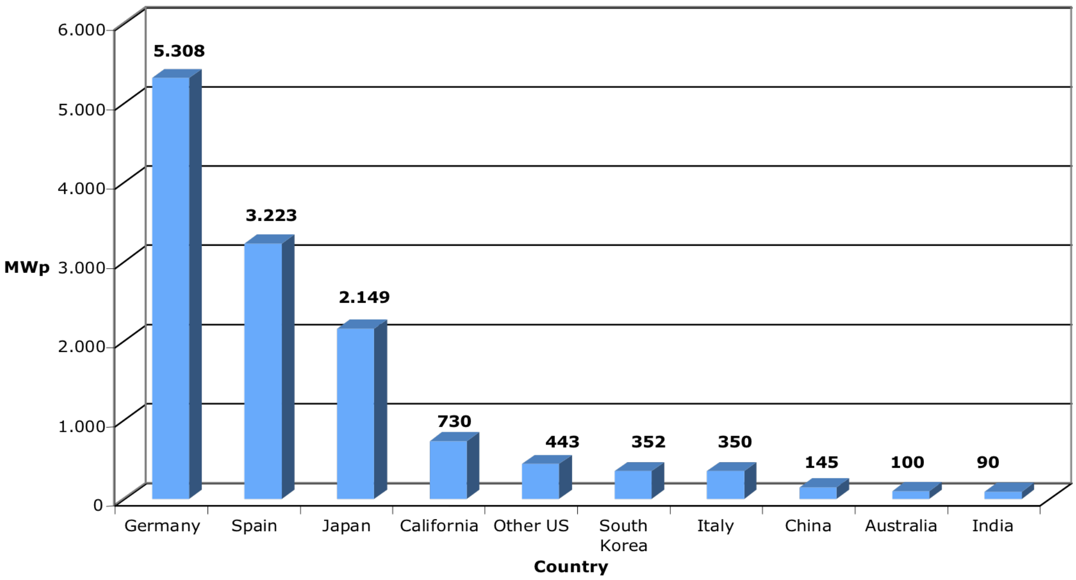
The Japanese PV market was pretty stable from 2001 to 2004 and from 2005 to 2007 it was marked by a sharp break and even a negative growth rate. In 2009, the Japanese PV market was revitalized by an annual growth rate of 110%.

In California, 2000 and 2001 were characterized by very high annual growth rates, because California was trying to recover PV underdevelopment of the 1980s and the 1990s. Despite this effort, California had a very small share of PV installations compared to Germany and Japan until 2003. But California's PV market was really boosted in 2008 when it registered a 90% annual growth rate. In 2008, California occupied the fourth position as for cumulative installed capacity worldwide, and also had the lion share among US states (62%). Finally, in 2009 California registered a far less brilliant growth compared to Germany and Japan, although in the United States it increased its share of cumulative installed capacity (67%).

Although Germany, Japan and California have historically made the most of the world's installed capacity, this pattern changed between 2001 and 2009. If in 2001 they accounted for 85% of total installed capacity, this percentage changed radically and in the end of 2009 the three countries accounted for 60% of the total world cumulative installed capacity.

We now compare the installed capacity in Germany, Japan, and California in 2008 and 2009, where we abserve that Germany has maintained the leading position through the two years. As illustrated in figure 3.17, in 2008 Germany was at the first position and Japan and the United States (including California and other US) followed behind, with 14% and 8%, respectively, of the global cumulative PV power installed capacity. In 2009, as it is described in figure 3.18, Germany was the leader of cumulative installed capacity (44%), followed by Japan (11%), and by California (5%). As for annual installed capacity, Germany installed in 2009 more than 50% of total added capacity, followed by Japan, 7%, and California, 3% (Fig. 3.19).

Figure 3.17 Cumulative installed capacity in Germany, Japan and California (2008)



Source: own calculations on EPIA data

Figure 3.18 Cumulative PV installed capacity (end of 2009)

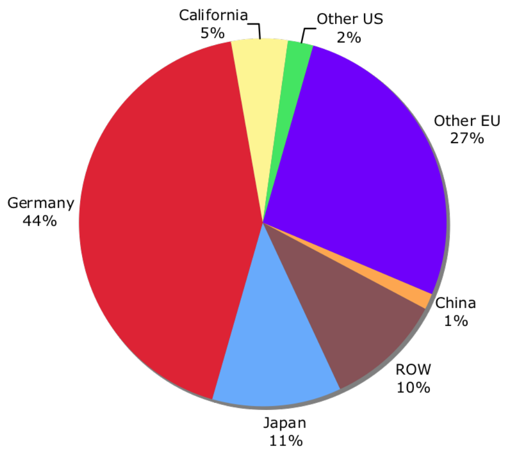
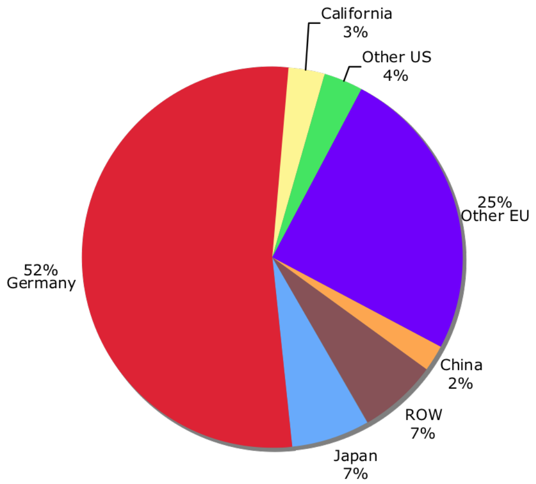
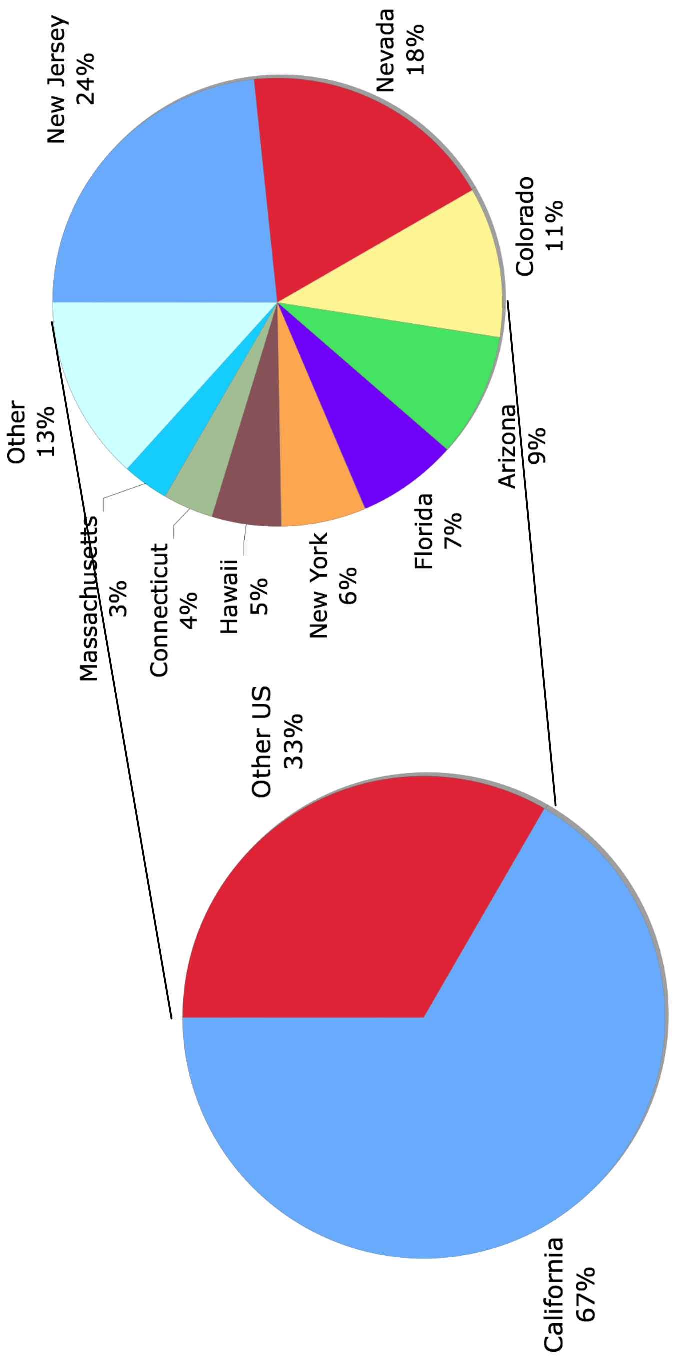


Figure 3.19 Annual PV installed capacity (2009)



Source 3.18 and 3.19: own calculations on EPIA data

Figure 3.20 US solar installations' shares of cumulative capacity in 2009.



Source: own calculation on SEIA data (including all grid-tied PV and CPV)

3.5.1 California

If we compare MW produced by top domestic PV companies from 2001 to 2009 (Tab. 3.1 to 3.4 - we here include the Chinese-US Suntech and the Arizona-based First Solar) with MW installed in California since 2000 (Tab. 3.6), we can observe that MW produced by PV companies in California surpassed by large MW installed through the all period. [317]

The disadvantaged US market demand was mainly originated by the 20-year gap of effective PV financial incentives and regulatory mandates from the beginning of the 1980s till the end of the 1990s. In fact, although the US was the first to introduce federal tax credits and an earliest form of a mandatory feed-in law in 1978, they did not trigger demand. It was only much later, starting from 1999, that renewable portfolio standard obligations and some feed-in tariff policies had been adopted state-by-state. California is today at the forefront of energy policy-making in the United States thanks to the establishment of a demanding renewable portfolio standard obligation in 2002, and of a well functioning PV program subsidies in 2006. Nevertheless, this was not enough to stimulate enough installation demand and the most of MW produced in California have been sent abroad.

If we analyse California with respect to other US states, we see that California's market-pull policies were more effective than those adopted by other US states in driving PV growth. It can be observed that from 2003 to 2009 California made around 50% of the total US annual installed capacity (Tab. 3.6). The RPS gradually stimulated the growth of PV installations with a CAGR of 38% from 2003 to 2009, thanks to the increase in demand for renewable power. The California Solar Initiative was also an important driver to the growth of installed capacity since 2007. The CAGR of PV installed capacity in California from 2007 to 2009 was as high as 52%. Nevertheless, California entered the group of leading PV markets only in 2008. This is reflected in the doubling of annual installed capacity with a growth rate of 88% from 2007 to 2008. Finally, despite a contingent growth rate of less than 23% in 2009 California remains by far the top US market for photovoltaics (Fig. 3.20).

In conclusion, according to our analysis California has been historically a *net exporter* of solar panels, although today the trend is changing thanks to more favorable regulatory policies and stimulus funds adopted in the aftermath of the 2008 economic turmoil. California is always at the forefront of research and development on most advanced solutions for solar cells, and also it is becoming an important market for PV installations, both to the benefit of domestic as well as foreign companies. "European and Japanese firms are investing and growing market share in this rapidly growing sector making the US increasingly an importer of renewables technology".[318]

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[317] As an example, in 2006 the MW manufactured by US national companies were two-fold the MW installed in the United States; in 2008 the MW produced by US national companies were around four-fold the MW installed in the United States.

[318] Nemet G. F., Kammen D.M. (2007): 7

3.5.2 Germany

If we compare MW produced by top domestic PV companies (Tab. 3.1 to 3.4) with MW installed in Germany (Tab. 3.6), we can observe that from 2001 to 2003 MW produced by leading domestic enterprises were around the same as MW installed in Germany. The situation radically changed in 2004 when MW installed capacity was much higher than MW produced by leading domestic companies. This trend continued through 2009.

If we analyze the impact of German market-pull policies on national companies' performance we can make a few observations. First, between the end of the first Roofs Program in 1995 and the launch of the second Roofs Program in 1999, German PV industry experienced a period of slow development.[319] Second, the adoption of the Renewable Energy Sources Act in 2000, amending the 1991 feed-in law, promptly drove photovoltaic installations by national companies. Third, in 2004 the new amendment to the feed-in law and the foreseen digression rates caused a rush to PV installations in the seven preceding months. However, once the revision entered into force it stimulated even more PV installations due to new tariffs for megawatt-sized plants that led to the implementation of large-scale solar PV systems.

Nevertheless, out of the total MW installed in Germany in 2005 only around a third came from domestic producers. This means that the amended feed-in law was a strong driver for attracting installations by foreign PV producers but did not have the same effects on leading domestic companies' performance. Interestingly, Q-Cells' export share increased yearly from 25% in 2005 up to 70% in 2008 when the best driving force was represented by the generous Spanish feed-in tariffs.[320]

Finally, the fourth observation about the impact of German market-pull policies on national companies' performance is the new revision of feed-in law in 2009 based on degression rates that caused a new rush to PV installations between its adoption in October 2008 and its entry into force in January 2009.[321] In 2009, MW installed grew to 3,800 MW and out of these only around a third was produced by the total of domestic companies (and 15% by leading domestic companies as in tab. 3.4).

In conclusion, in the period 1991 to 1995 the first Roofs Program and, only marginally, the first feed-in law were the main drivers for the establishment of an embryonic PV industry in Germany. From 1995 to 1999, the German industry experienced a "dark age" due to lack of subsidies to PV and the absence of a long-term plan on the development of this industrial sector by the German Government. From 1999 to 2004, the combination of favorable loans for PV installation and generous feed-in tariffs were very important drivers to the domestic PV industry growth. In 2004, the revised feed-in tariffs made of Germany the world leader of installed capacity (300% annual growth) due to the high attractiveness of foreign investments in the Germany photovoltaic field. In 2009, the new amended feed-in law did not interrupt the

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319 M. Karl (2005). *Renewable Energy Policy and Politics: A Handbook for Decision-Making.* Earthscan Publications Limited, London: 250.

320 Q-Cells' export share: 2003: 30%, 2004: 25%, 2005: 37%, 2006: 53%, 2007: 61%, 2008: 70%.

321 Driving in the last three months of 2008 almost all the 42% annual growth rate in PV installed capacity.

good wave of investments by foreign PV companies and confirmed Germany as a *net importer* of solar panels and the champion of PV installation.

3.5.3 Japan

If we compare MW produced by leading domestic PV companies (Tab. 3.1 to 3.4) with MW of installed capacity in Japan (Tab. 3.6) we can observe that since 2001 MW produced by Japanese leading PV companies have been higher than MW installed nationally. The leading Japanese PV companies in 2001 produced 162 MW of which 135 MW were installed in Japan. The gap between MW production and installation grew progressively up until 2009 when of the almost 1 GW produced by domestic manufacturers only a half was installed in Japan.

Japan triggered PV market growth in the 1990s due to two specific solar energy policies: the 1992 voluntary net metering program and the Roofs Program of 1994. In particular, the Roofs Program truly stimulated an impressive residential PV installation in Japan and in ten years 200 MW had been installed, out of a total 272 MW. This favorable situation that boosted the national solar PV industry from 1994 to 2004 changed and from 2004 to 2008 PV installation was stable if not even negative. (If the CAGR from 2000 to 2004 was as high as 25%, the CAGR of installed capacity from 2005 to 2008 was negative, -7%). This was in part due to the expiration in 2005 of the Roofs Program and the fact that a similar program was not restored up until January 2009. In 2009 the situation radically changed thanks to a new PV Roofs Program that caused the 110% annual growth rate in the Japanese installed capacity.

In conclusion, in Japan good performance of leading domestic companies has not been driven only by market-pull policies. According to our analysis, Japan is a PV *net exporter* and the Japanese PV sector has grown mainly thanks to reasons of industrial and technology policies. The most successful policy in Japan is the Roofs Program that is a subsidy covering the up-front cost of installing a solar panel and therefore can be considered more as a technology-push rather than a market-pull policy.

Chapter 4: A Critical Exploration of the Synergy Between Technology-Push and Market-Pull Policies

The position of the investigated companies at the top of the global PV manufacturers' ranking is the demonstration of the strong correlation between the successful national technology and energy promotion policies and the thriving performance of their companies. As observed in the previous chapters and in figure 3.1, it is undisputable that Germany, Japan and California are the states that not only contributed to the discovery, development and deployment of PV technology, but also implemented continuous technology policies and promotion policies that stimulated their PV market growth.

4.1 California

Despite 20-year gap of effective PV financial incentives and regulatory mandates combined with poor R&D investment, since the late mid-2000s California is experiencing the deepest revival of the solar energy industry and its PV companies are flourishing the most compared to other US States. This is due to a more balanced and positive synergy of technology and market-pull policies.

On the one side, the university system is one of the most advanced in the United States, and in the world, and the university-industry cooperation combined with the presence of many venture capitalists is definitely conducive to PV industry growth. On the other side, the renewable portfolio standard obligations have been pivotal for the development of California as one of the top world's PV market. The 20% quota of renewable energy to be produced in California by 2010 might not have been reached yet, but the effort has been huge and the target is not too far away.[322] The quota of 33% by 2020 is a very demanding target but it should not be difficult to reach if the path of growth continues with the same pattern. The California Solar Initiative is also a very important stimulus to PV installation in California, with a set goal of 3,000 MW by 2017, and the same we can say for the net metering system, that is an additional incentive to any rebates received under the Solar Initiative.

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[322] The California's Investor-Owned Utilities collectively served 15.4% of their 2009 electric load with renewable energy under the RPS, up from 13% in 2008.

Although both these policies have been successful, in our opinion an important issue need to be solved in order for California to get the most out of its best market-pull policy, the renewable portfolio standard regulation. This is the coordination of RPS with the net metering system that should be counted towards RPS obligations. The fact that RPS covers only large-scale PV plants of more than 20 MW is restrictive and excludes a big share of the market that is made of distributed and residential generation.

Moreover, a feed-in tariff system in California, or in other US States, is not an option because competition and the free market are too valued in the United States, therefore this policy is not politically viable. However, in our view, the California FIT scheme as it is now designed has important drawbacks because it does not provide an incentive for the deployment of efficient technologies. California has historically been an innovator in supporting commercial application of solar technologies, therefore this should at least be taken into account in the reform of the California feed-in tariffs system that could be designed by adding a higher incentive to more efficient PV technologies at source.[323]

At the federal level there are no requirements for solar energy, and the 30% Investment Tax Credit is the only incentive for boosting the solar technology industry in the United States. In our view, its expiration in 2016 should be delayed in order not only to guarantee a stable and consistent policy, that is conducive to investments in the PV industry, but also because it has been demonstrated that state RPS is more effective when it is accompained by federal ITC. Also, the loan guarantee program is not, in our opinion, a functional policy because it appears as a hidden subsidy whereas, in order to really boost the solar industry of already commercialized PV technologies, subsidies should be equally available to all. In theory, at the federal level the adoption of a RPS system would be a priority to give an equal and official and common framework to the effort of US States towards green energies. Nevertheless, in our view this is not a viable option both politically and from a generation standpoint. Every US State is different as for energy resources, industrial system and for the political will to follow the green path. California is at the forefront in the battle to climate change and it is very likely that it will remain the State with more renewable and solar energy generation and relative technology improvements.

The high electricity price in California is another fundamental driver to the growth of a solar energy market and the fact of putting a price on fossil fuels would make the advantage of consuming renewable and solar energy even bigger. In 2008, the total in-state California solar

[323] In 2009, CPUC proposed a reform of the FIT in California that addressed two major issues at stake, but not the issue of better incentives for more efficient technologies. The proposal entailed, first, whether the project size and sales eligible for the FIT should be increased from 1.5 MW to 20 MW to include PV project sizes that are uncovered under CSI and RPS. Second, the adoption of a competitive market approach for setting the FIT price. Within that approach, CPUC would adopt a Renewable Auction Mechanism (RAM) for price determination. RAM is a form of auction, where projects are eligible to submit non-negotiable price bids. The buyer then selects winning projects based on the lowest price. The overall objective of the new policy is to offer every reasonable opportunity for stakeholders to meet California's many goals and targets, including RPS, GHG, and others.

power generation share was as small as 0.2%, and it doubled in 2009. This percentage is not too big if we consider that in 2008 the overall California's renewable energy power generation share was 10.6%. However, in our view, by taxing "brown" energy this percentage of green and solar energy generation could only further increase.

4.2 Germany

The German leadership in global PV installed capacity is certainly due to a synergy of market policy and technology instruments: a strong RD&D policy and a very well organized research system combined with preferential financial incentives.

The feed-in tariffs system in Germany has been by far the most successful market-pull policy and the main driver for investments in solar energy. The critics raised in a 2009 report by the Rheinisch-Westfãlisches Institut (RWI)[324] concerning negative effects of the Renewable Energy Sources Act, such as distortion of competition among renewable energy producers and the locking-in of existing silicon-based technologies, are not shareable in our opinion. In fact, to justify this view RWI stated that the thin-film solar cell technology for PV modules is not gaining ground because of the massive existence of silicon-based PV modules. The fact that with respect to thin-film production capacities Germany was one of the leading countries in 2009, confirms our view that it is the market to decide the future of different technologies and the feed-in tariffs system is the best policy adopted in Germany.

In our view, Renewable Energy Sources Act is fully intentionally open to all technologies, and tariffs for electricity from PV installations are paid irrespective of the technology used. The German Government does not assume the right to decide which PV technology is the better or more appropriate option to generate electricity. Consumers are therefore free to decide which kind of module they want to buy and which technology suits them best.

The reduction of feed-in tariffs in July 2010 was in line with the tariffs' degression system that is correlated with learning curves effects and PV technology innovation.[325] This is again the clear demonstration of the very good synergy of technology and market-pull policies in Germany.

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[324] RWI (2009), "Economic Impacts from the promotion of renewable energies: The German experience", Final Report, Essen

[325] "Feed-in tariff rates were reduced by 13 percent for rooftop installations and eliminated for cropland field installations from July 1. At the same time, conversion areas saw a reduction of 8 percent and all other areas were decreased by 12 percent. Beginning October 1, these rates will be reduced by a further 3 percent. Still, the new tariffs remain highly attractive, with rates ranging from 25.02 – 34.05 €c/kWh for installations connected before October 1 and 24.26 – 33.03 €c/kWh for those connected during the remainder of the year. The changes mark a further shift towards the rooftop segment by abandoning field installations on cropland and increasing the attractiveness of the own consumption bonus for small and medium-scale rooftop installations. This bonus is paid to rooftop installation owners of systems smaller than 500 kWp who intend to use the energy they generate." Source: German Trade & Invest.

4.3 Japan

Japan is a different example of a country that has invested a lot in RD&D throughout the history of its PV industrial development, but it did not do the same as for market-pull policies. Japan counted on a "niche" residential PV market implemented through a very functional residential PV program and a voluntary net metering system. Therefore, the focus was on the investment in research and development to make the national companies more competitive in terms of technology advancement rather than on focusing on national PV demand through market-pull policies.

The situation is slightly changing since 2009, when a new subsidy program and a more advantageous net metering system were implemented. The adoption of a new mandatory net metering system with a buyback price set twice as high as the voluntary buyback price will certainly be an important stimulus to new installed capacity in Japan. In our view, these two new policies could have an important effect on Japanese PV technology market, namely the transformation of Japan from a PV exporter into a PV market, with the subsequent growth of the already very well developed national PV industry.

Discussions over the adoption of a feed-in tariff have been undertaken by the Japanese government since the end of 2009, and METI sought to start FIT in 2012.[326] In our view, there exist too many worries, however, that this policy would push electricity prices up overall.[327] With scarce domestic energy resources, Japan has experienced high electricity prices for much of the last century. Therefore, the introduction of this policy in Japan is still contentious because the consumers will have to support the major burden. Moreover, if we consider that since the deregulation period, Japanese electricity market has always been characterized by an approach towards consumer welfare,[328] the adoption of a feed-in tariff in Japan seems to us quite unlikely. Nevertheless, the foreseen adoption of a feed-in tariff system in Japan should be taken into consideration for future investigation. It will likely cause important changes in supporting financial measures that might have important repercussions on PV installation and PV industry developments in Japan and the world.

Furthermore, in our opinion RPS policy effects in Japan could grow in importance as for solar energy. The most important characteristic that distinguishes the RPS scheme in Japan from the one in California is that the obligation to produce a defined amount of electricity from

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[326] According to METI the initial rate paid to owners of solar energy systems in the feed-in tariff scheme will be around JPY 50 per surplus kilowatt hour produced, double the current rate of JPY 24 ($0.25/kWh) and the program will have an initial duration of 10 years.

http://www.meti.go.jp/english/policy/energy_environment/renewable/pdf/FIT_option.pdf

[327] The cost of introducing the system would be passed on to consumers evenly, resulting in a rise in electricity fees per family of up to JPY100 a month.

[328] Goto M., Yajima M., *op cit.*: 642: "We should always take into account that our ultimate aim for electricity restructuring is to improve efficiency (…) that can provide us with reliable energy at efficient prices, which eventually leads to an increase in consumer welfare. Competition is merely a tool to achieve the aim, not our supreme goal".

renewable energy sources is applied directly to technology producers and not on electricity suppliers. This would constitute an important stimulus to technology innovation in the Japanese PV field because it could be linked to incentives based on technology performance.

In our view, after having triggered PV growth in the 1990s, and in order to become once again the world leader in solar generation and to reach its demanding PV targets, Japan needs to bring price down substantially through continuous technology innovation and creation of more domestic demand.

4.4 Lessons Learned

Countries characterized by a market-oriented economic and political culture tend to choose the most market-based instruments. This is the case of the United States and California. Unlike feed-in tariffs that guarantee purchase of renewable energy at a fixed price, RPS programs tend to allow more price competition between different types of renewable energy, although they can be limited in competition through eligibility for RPS programs. Those supporting the adoption of RPS mechanisms, such as California and other 29 US States, claim that market implementation will result in competition, efficiency and innovation that will deliver renewable energy at the lowest possible cost, and help accelerate the move toward grid parity with conventional fossil fuels' energy.

Countries that lack domestic energy supply and manufacturing capabilities in fossil or nuclear power sectors tend to be strong promoter of a national renewable energy industry. As observed, this is the case of Japan that lacking a its own fossil fuel production was the first to adopt a program aimed at technology innovation and market deployment of solar technologies in the aftermath of the 1973 Oil Crisis. Similarly, California lacks its own domestic fossil fuel supply and also has banned the approval of new nuclear reactors since the late 1970s. Thus, the attention to renewable energy from solar and other renewable sources both in Japan and Caliornia is self-evident. The same occurred in Italy, where renewable energies have been promoted since 1992 under a FIT program (CIP 6/92) that was inspired by the US PURPA experience. CIP 6/92 was aimed at reducing the country's growing dependence from energy imports in the aftermath of of the nuclear moratorium of the mid-1980s. This system was substituted in 1999 with a quota system based on tradable green certificates (TGC) similar to US RPS systems. However, Italy was also the only country to implement a feed-in tariff specifically designed for PV systems since 2005, the so-called "Conto Energia", that has largely contributed to the growth of Italy among the first global PV markets especially since 2008.

In the middle of the first two positions are the countries with increased dependance on imported energy and little fuel diversity. These countries tend to be more concerned about energy security and climate change issues, encouraging renewable energy deployment. In Germany this is the prevailing attitude that was further stimulated by a phase out of the use of nuclear power in 2000 and explains why Germany was among the first countries to promote a generous feed-in tariffs system. In Germany concern about greenhouse gas emissions is one of the main drivers to the growth of a national solar industry, both through market-pull mechanisms and growing PV installations with immediate effect on GHG emissions, and through technology-push policies for PV industry growth with future effects on GHG emissions.[329]

Other reasons behind investments in the PV technology industry are: the promotion of domestic a domestic PV industry because of its benefits for employment and profits; the creation of a competitive solar industry because of its trade benefits; and the creation of innovative PV solutions and licensing technology to both domestic and foreign firm. All these goals should be taken into account when evaluating energy and technology policies. Sometimes these targets are all bundled together and some other time they have independent trajectories.

Japan is the demonstration that international trade benefits and intellectual properties are the main drivers to the growth of a national PV industry, whereas the promotion of domestic solar use is not pivotal. Japan is more focused on R&D and patent creation, thus favoring a long-term strategy for the development of one of the most competitive PV industry. As already observed, numerous Japanese inventors have applied to the European Patent Office in order to counteract European competition and are the winner in terms of number of PV patents. In Germany the main reasons for growing investments in the PV industry are those mentioned above, i.e. the immediate and future positive effect on greenhouse gas emissions. Also, Germany is the champion of PV installations and this is certainly beneficial for growing employment and profits. California bundles together all different goals in the most comprehensive way. The Golden State has been historically a net exporter of PV technology, although today domestic solar use is growing thanks to better market-pull policies. This is leading toward the promotion of green jobs and higher profits. Trade benefits are fundamental economic reasons behind investments, but in California they are dwarfed by activity of creation and licensing of PV technology. Finally, in California concerns about greenhouse gas emissions are also very important thanks to one of the most restrictive state regulations in the United States.[330] From these observations we can assume that it is not always necessary to promote domestic solar installations in order to realize the international benefits of trade and intellectual property, and that some countries would be better off focusing on R&D while others promoting domestic PV use by enacting feed-in tariffs policies and renewable portfolio standards.

FIT policies are being experimented within the United States and in California, but certainly not as comprehensively, nor at the same scale than in Germany, Italy or Spain. One of the main reasons for this poor diffusion can be identified in the fact that unlike the German law, California's tariff rates are based on time-of-delivery, rather than the generation cost of individual technologies. Therefore, the payment levels offered remain too low to drive

[329] Generating 1 kWh of electricity from fossil fuels emits on average about 600 grams of CO2-equivalent (including other greenhouse gases). On average, it can be considered that each kWh produced by PV spares 600 grams of CO2-equivalent, even taking the energy used to produce PV panels into account.

[330] A.B. 32, The Global Warming Solutions Act of 2006, http://www.arb.ca.gov/cc/ab32/ab32.htm

development in most renewable energy technologies, like for example photovoltaics. This means that all technologies are offered the same price, but that this price varies depending on whether the electricity is generated during peak or off-peak times. Another reason is that California has a cap on both project and program size, thus hindering the developers' ability to harness economies of scale. These size caps also limit the ability of the FIT to drive large-scale renewable energy deployment in the State of California putting at risk the development of a distributed renewable energy generation. Moreover, the fact that FIT system in Germany and Italy provides for longer-term contracts guaranteed for 20 years is a sign of policy stability to investors. Also, it is designed to allow for a high degree of price differentiation, allowing renewable energy investments to be profitable in a wide variety of technology types.

In this framework, Italy should be taken as a case of best practice because its "Conto Energia" uses an innovative system that pays among the highest prices for solar PV in Europe, embedding a production subsidy in the price offering, and therefore allowing for reasonable profits. It cannot be defined as a common feed-in tariff, but instead it constitutes a very peculiar - it does only apply to photovoltaics systems - and an important stimulus to the production of renewable electricity as well as for the attractiveness of PV investments. Also, whereas FIT policies established in other European countries are more focused on encouraging the sale of renewable energy power back into the grid rather than using it for self-consumption - Germany introduced a net metering system only in 2009 - Italy introduced a net metering system back in the 1990s, the so-called "Scambio sul Posto", with the installation of the first solar panels connected to the grid.[331]

German and Italian experiences provide lessons learned that might be useful for future policy adoption and implementation in other countries, and especially if a new federal feed-in tariff policy will be adopted in the United States, or a reform of California's feed-in tariff policy will be undertaken. In the United States, FIT policy could be used as tools to help meet and promote pre-existing state RPS objectives. First, the FIT could be an alternative to the current method for awarding contracts, which is based on competitive solicitations. The mechanism most commonly used to meet the RPS mandates in the United States is competitive solicitations, or tendering, where project developers are required to put forward competitive bids to obtain contracts. The problem with bidding is that the solar industries participating in a tendering are allowed in case of victory of the possibility to build a new plant, but with serious limitations in terms of revenues. If the industry does not foresee any important revenue out of their projects than the risk is that it will choose to build the plant with other production incentives. In this case industry would rather choose ITC or the new DOE Loan Guarantee Program. Another option would be to have the two policies acting in parallel, with FIT targeting specific technology types or project sizes. For example, FIT policies could be offered to smaller scale projects while leaving the basic competitive solicitation mechanism for utility-scale projects. This is the approach currently employed in California where FIT applies to PV installations from 1 MW to 20 MW, whereas RPS applies to large-scale PV plants larger than 20 MW. The architecture of feed-in tariffs is very important. Among other

[331] If in 2008 the share of PV over total electricity consumption in Italy was just 0.006%, this percentage will grow at least until 2013 when the actual "Conto Energia" is doomed to expire.

adventaged, designs that encourage distributed generation may allow the facilities to be located in areas where they can connect to the existing grid and therefore not be slowed by the need to site new transmission lines.

This policy interaction between FIT and RPS could be transferred to other US States, but only when a legal issue will be settled. The division of authority in setting electric rates in the United States with the federal government having authority to set wholesale rates and the state governments having authority to set retail rates significantly complicates the adoption of feed-in tariffs in the United States. While states encounter limitations to adopt feed-in tariffs under existing federal law, widespread use of this approach to encourage solar energy generation likely relies on clarification of Federal Energy Regulatory Commission precedents and rulemakings or new administrative decisions by FERC, or even on the passage of new federal legislation.

4.5 Conclusions

In our view, subsidies to PV can be beneficial but not those that favor one technology over another. Subsidies that try to choose a winner would only work if at the stage of research and development some government official could reliably know which technologies will survive the “valley of death” and would contribute to its market deployment. Although this hypothesis is difficult to realize, government support of certain technology that could have broad application in the market is good and necessary. However, the market remains the best driver to stimulate technology innovation since the return on investment is heavily dependent on the performance of a PV system.

Japan makes a very good example of favorable subsidies for PV promotion. Its early investment in the Sunshine Program was focused to develop a national solar industry (PV and CSP) with the aim of reaching energy independence in the aftermath of the 1973 Oil Crisis. Through the first and second RD&D Sunshine Programs the Japanese legislators relied on PV as a technology that would survive the “valley of death” and they contributed to make Japanese PV industry competitive worldwide. Subsidies such as those of the successful “Residential PV System Dissemination Program” were implemented within a comprehensive strategy of PV industrial development.

As opposed to subsidies scheme, renewable portfolio standards would rely on free market to ensure that PV is developed in the most economical way. This policy, as it has been adopted in California and other US States, is in our view the best market-pull instrument because it drives technology costs down and makes the consumption of renewable and solar power more affordable and therefore more spread. Moreover, RPS is a stable and consistent renewable policy because it provides a long-term and predictable market for renewable energy as a whole, without selecting a specific technology.

Feed-in tariffs are also very effective market-pull instruments to encourage the diffusion of renewable and solar energy and to help accelerate the move toward grid parity. In order to be more effective, feed-in tariffs should be designed as they have been in Germany, or in Italy, and should therefore contemplate degression rates well correlated with technology improvements and cuts in production costs.

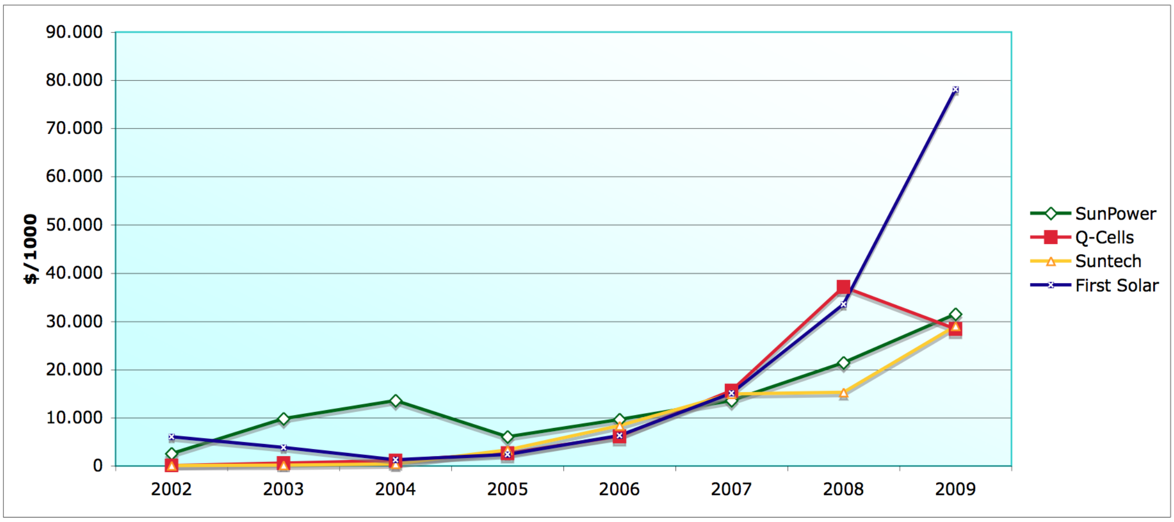
Research and development is fundamental for reaching technology innovation and getting closer to grid parity. It is therefore a responsability of all governments involved in renewable energy promotion to invest in R&D, either through direct or indirect instruments. Short-term R&D must focus on making the PV industry more competitive. Rapid development and high production volumes are crucial to establish industrial leadership. Industry will usually push for investment in short-term R&D and as the PV industry grows, this pressure may grow. Governments should therefore take a medium and long-term perpective.

Policy measures directed toward the diffusion of solar cells with the purpose of cost reduction need to be sustained in order to set in motion a process of self-sustained growth. A stable policy environment for boosting solar energy development, made of a synergy between continuous medium and long-term R&D technology policy and favorable but progressively decreasing economic support schemes, is the key for the self-sustained growth of PV industry in Germany, Japan, and California and in any country investing in renewable energy technologies.

APPENDIX A

R&D EXPENDITURE AND R&D INTENSITY

R&D expenditure (2002 - 2009).



Source: Datastream Thomson Reuters (own calculation)

R&D intensity - R&D as percentage of revenue (2002 – 2009).

Company/Year	*2002*	*2003*	*2004*	*2005*	*2006*	*2007*	*2008*	*2009*
First Solar (USA)	1230%	119.7%	9.17%	4.94%	4.71%	3%	2.69%	3.74%
SunPower (USA)	62.44%	196.12%	124.35%	7.65%	4.09%	1.75%	1.49%	2.07%
Suntech Power (China)	2.03%	1.06%	0.55%	1.49%	1.4%	1.11%	0.8%	1.71%
Q-Cells (Germany)	0.41%	0.95%	0.62%	0.75%	0.86%	1.25%	2.13%	2.48%
Sharp (Japan)	6.98%	6.7%	6.15%	5.83%	5.52%	6.07%	5.74%	6.87%

Source: own calculations on Datastream Thomson Reuters Data

Notes: Sharp data refer to its entire portfolio of products

APPENDIX B

EBITDA MARGINS

The table hereafter describes the Ebitda margins of the five investigated companies. We don't intend to make a comparison among companies' data but we would like instead to observe these data as a very important measure of the profitability of the single company. Ebitda margin depends on the industrial sector. Despite the top five PV companies are very similar for dimension and they are all in the same industrial sector, with the sole exception of Sharp whose data refer to its entire production, data differ quite a lot.

In particular, Q-Cells is the company that shows the most fluctuating data, especially in 2009, when the Ebitda margin was negative and this was due to the cut in sales and production forecast after customers delayed deliveries of Q-Cells products in 2008. This made Q-Cells' shares value decrease from an average of about 40$ in the late 2008 to an average of 15$ in 2009.[332] First Solar was founded in 1999, and started production in 2002, and the negative trend in the Ebitda margins in 2003 and 2004 was due to a very high R&D intensity and limited net sales, especially in the first years of the history of First Solar. A similar observation can be made for SunPower in 2003 and 2004 when a negative trend in the Ebitda margin was due to poor net sales and high R&D intensity.

[332] http://www.google.com/finance?q=q-cells, http://www.greentechmedia.com/articles/read/q-cells-cuts-sales-forecast-after-customers-delay-deliveries-5340/

Ebitda/net sales of the top 5 PV companies (2002 – 2009)*.

Company /Year	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**
First Solar	N/A	-703,02%	-108,91%	-5,74%	15,12%	36,26%	42,19%	39,18%
SunPower	-71,27%	-234,11%	-196,24%	-0,96%	21,70%	8,29%	15,48%	11,88%
Suntech Power	-1,12%	14,65%	26,04%	19,88%	20,91%	16,06%	9,58%	15,40%
Q-Cells	12,45%	16,01%	17,77%	26,15%	28,08%	28,39%	25,62%	-88,31%
Sharp	8,39%	9,74%	11,35%	12,31%	12,11%	11,60%	12,58%	3,67%

Source: Thomson Reuters Datastream, London

Notes:

* Ebitda is calculated based on (pretax inc+interest exp (purely interest expense) + Depreciation & Amortization (Excluding Impairments)+ Interest Capitalized.

**These data refer to all Sharp products and not only solar cells.

REFERENCES

Alic J., Mowery D.C., Rubin E.S. (2003). “US technology and innovation policies. Lessons for climate change”, *Pew Center on Global Climate Change*, Arlington, VA

Anadon L.D. *et al.* (2009). “Tackling US energy challenges and opportunities”, Energy Technology Innovation and Policy Group, Belfer Center for Science and International Affairs, *Harvard Kennedy School*, Cambridge, MA

Becquerel E. (1839). “Mémoire sur les effets électriques produits sous l’influence des rayons solaires”, *Comptes Rendus de l’Académie des Sciences* 9, Paris: 561-567

Bereny J.A. (1977). “Survey of the emerging solar energy industry”, Solar Energy Information Services, Francis deWinter (ed.), Atlas Corporation, San Mateo, CA

Berwind J. (2009). *Investing in Solar Stocks,* Mc Graw Hill, New York

BMU (2007). “Innovation Through Research”, Annual Report, Berlin

BMU (2008a). “Innovation Through Research”, Annual Report, Berlin

BMU (2008b). “Economic Analysis and Evaluation of the Effects of the Renewable Energy Act”. 03MAP113, Berlin

BMU (2009). "Renewable Energy Sources in Figures: national and international development", Berlin

BMU (2010). “Development of Renewable Energy Sources in Germany 2009”, based on Working Group on Renewable Energies – Statistics, Berlin

Bolinger M., Wiser R., Cory K., James T. (2009). “PTC, ITC, or Cash Grants? An Analysis of the Choice Facing Renewable Power Projects in the United States”, Joint projects by LBNL-1642E and NREL/TP-6A2-45359, NREL, Golden, CO

Bolinger M., Wiser R. (2003). “Learning by Doing: The Evolution of State Support for Photovoltaics”, LBNL-52398, Berkeley, CA

Borenstein S. (2008). “The Market Value and Cost of Solar Photovoltaic Electricity Production", Center for the Study of Energy Markets, Working Paper N. 176, *University of California Energy Institute,* Berkeley, CA

Bradford T. (2006). *Solar Revolution: The Economic Transformation of the Global Energy Industry,* The MIT Press, Cambridge, MA

Bradford T. (2008). *La Rivoluzione Solare: Perché l’Energia del Futuro Viene dal Sole*, Brioschi Editore, Milano, 2nd ed.

Britt R. (2008). “Universities Report Continued Decline in Real Federal S&E R&D Funding in FY 2007”, National Science Foundation, NSF 08-320, August 2008.

BSW Solar (2010). “Statistic data on the German Photovoltaic Industry”, June 2010

Buzbee W.W. ed. (2009). “Federal Floors, ceilings, and the Benefits of Federalism’s Institutional Diversity”, in *Preemption Choice: The Theory, Law and Reality of Federalism’s Core Question,* Cambridge University Press, Cambridge, NY

Carovita G. (2009). “Fotovoltaico Nanotech”, *Il Sole24 Ore*, 28/05/2009: 15

Chapin D., Fuller C., Pearson G. (1954). "A New Silicon p-n Junction Photocell for Converting Solar Radiation into Electrical Power”, *Journal of Applied Physics*, vol. 25, issue 5: 676-677

Clean Energy Patent Growth Index (2009). Cleantech Group, Heslin Rothenberg Farley & Mesiti P.C., http://www.cepgi.typepad.com/

Cory K., Couture T., Kreycik C. (2009). “Feed-In Tariff Policy: Design, Implementation, and RPS Policy Interactions”, NREL/Technical Report-6A2-45549, Golden, CO

Couture T., Cory K. (2009). “State Clean Energy Policies Analysis (SCEPA) Project: An analysis of Renewable Energy Feed-in Tariffs in the United States”, NREL/ Technical Report-6A2-45551, Golden, CO

CPUC (2008). “California’s Renewables Portfolio Standard”, November 2008, San Francisco, CA

CPUC (2009). "California Solar Initiative", Staff Progress Report, October 2009, idem

CPUC (2010a). "Introduction to the Net Energy Metering Cost Effectiveness Evaluation", March 2010, idem

CPUC (2010b). "California Solar Initiative", Annual Program Assessment, June 2010, idem

CPUC (2010c), "Renewables Portfolio Standard", Quarterly Report, 3rd Quarter 2010, idem

Darghouth N., Barbose G., Wiser R. (2010). "The Impact of Rate Design and Net Metering on the Bill Savings from Distributed PV for Residential Customers in California", LBNL-3276E, Berkeley, CA

DOE - Office of Science (2005). "Basic Research Needs for Solar Energy Utilization", Report on the Basic Energy Sciences Workshop on Solar Energy Utilization: 13

Dosi G. (1982). "Technological paradigms and technological trajectories: a suggested interpretation of the determinants and directions of technical change, *Research Policy* (11) 3: 147-162

DSIRE (2010). Database of State Incentives for Renewables and Efficiency, North Carolina Solar Center and the Interstate Renewable Energy Council (IREC)

EEG (2000). "Gesetz für den Vorrang Erneuerbarer Energien - Erneuerbare-Energien- Gesetz – EEG", (Act on Granting Priority to Renewable Energy Sources), Federal Law Gazette (Bundesgesetzblatt) 2000 I, March 2000, Bonn

EEG (2004). "Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector", Federal Law Gazette (Bundesgesetzblatt) 2004 I No. 40, July 2004, Bonn

EEG (2008). "Act Revising the Legislation on Renewable Energy Sources in the Electricity Sector and Amending Related Provisions – Renewable Energy Sources Act – EEG 2009", Federal Law Gazette (Bundesanzeiger) 2008 I No. 49, October 2008, Bonn

EPIA (2009a). "Global Market Outlook for Photovoltaics until 2013", 04/2009, Brussels

EPIA (2009b). "Set for 2020", 06/2009, Brussels (http://www.setfor2020.eu/)

EPIA (2010a). “Global Market Outlook for Photovoltaics until 2014”, 05/2010 update, Brussels

EPIA (2010b). “Unlocking the Sunbelt Potential of Photovoltaics”, 2nd ed., 10/2010, Brussels

EREC (2008). “Renewable Energy Technology Roadmap: 20% by 2020”, 11/2008, Brussels

Elkind E.N. (2009). “In our Backyard, How to Increase Renewable Energy Production on Big Buildings and Other Local Spaces”, Berkeley Law & UCLA Law, UCB & UCLA, CA

EurObserv’ER (2009). “Photovoltaic Barometer”, March 2009, Paris

EurObserv’ER (2010). “Photovoltaic Barometer”, April 2010, Paris

European Commission (1997). “White Paper for a Community Strategy and Action Plan-Energy for the Future: Renewable Sources of Energy”, COM(97) 599 final

European Commission (2000). “Green Paper - Towards a European strategy for the security of energy supply”, COM(2000) 769 final

European Commission (2006). “Green Paper - Follow-up action: Report on progress in renewable electricity”, COM(2006) 849 final

European Parliament and Council (1996). “Directive 96/92/EC concerning common rules for the internal market in electricity”, in OJ L 27, 30.1.1997.

European Parliament and Council (2001). “Directive 2001/77/EC on the promotion of electricity produced from renewable energy sources in the internal electricity market”, in OJ L 283, 27.10.2001, and its amendment acts, in OJ L 236, 23.9.2003 and OJ L 363, 20.12.2006.

Farber D.A. (2009), “Legal Guidelines for Cooperation between the European Union and American State Governments”, *UC Berkeley Public Law Research Paper* No. 1468643, Berkeley, CA

Federal Ministry of Education and Research (BMBF) (2006a). “Research and Innovation in Germany in 2006”, Bonn - Berlin

Federal Ministry of Education and Research (BMBF) (2006b). “The High-Tech Strategy for Germany”, Bonn - Berlin

Federal Ministry of Education and Research (BMBF) (2008). “The High-Tech Strategy on Climate Protection”, Bonn - Berlin

Freeman C., Perez C. (1988). “Structural crises of adjustment, business cycles, and investment behavior”, in Dosi, G., Freeman. C., Nelson, R., Silverberg, G., Soete, L. (Eds), *Technical Change and Economic Theory*, Pinter, London.

Friedman T.L. (2008). *Hot, Flat, and Crowded,* Allen Lane, Penguin Books, London

Fthenakis V. (2004). “Life cycle impact analysis of cadmium in CdTe PV production”, *Renewable and Sustainable Energy Reviews*, vol. 8: 303-334

Fthenakis, V., Alsema, E. (2006). “Photovoltaics Energy Payback Times Greenhouse Gas Emissions and External Costs: 2004-early 2005 status,” Progress in Photovoltaics: Research and Applications, vol. 14, no. 3: 275-280

Fthenakis V. *et al.* (2009). “The technical, geographical, and economic feasibility for solar energy to supply the energy needs of the US”, Energy Policy, vol. 37: 387-399

Fusaro P.C., Vasey G.M. (2006). *Energy and Environmental Hedge Funds - The New Investment Paradigm*, John Wiley and Sons Finance, Singapore

Gereffi G., Dubay K. (2008). “Concentrating Solar Power”, *Center on Globalization Governance and Competitiveness,* November 2008, Durham, NC

Gerrard M.B. (ed.) (2007). *Global Climate Change and US Law*, American Bar Association, Washington

Goodstein D. (2004). *Out of Gas: The End of the Age of Oil*, Norton, New York

Goto M., Yajima M. (2005). “A new stage of electricity liberalization in Japan: Issue and expectations”, in *Electricity Market Reform, an International Perspective,* Sioshansi F. & Pfaffenberger W. eds., Elsevier, Oxford: 617-643

Grace R.C. *et al.* (2008). “California Feed-In Tariff Design and policy Options”, Second Draft. CEC-300-2008-003-D. California Energy Commission, Sacramento, CA

Green M.A. (2000). *Power to the People: Sunlight to Electricity Using Solar Cells*, University of New South Wales Press, Sydney

Green M.A. (2003). *Third Generation Photovoltaics, Advanced Solar Energy Conversion*, Springer-Verlag, Berlin, Heidelberg

Green M.A. (2004). "Third-Generation Solar: Future Photovoltaics," *Renewable Energy World:* 203

Grubb M. (2004). "Technology Innovation and Climate Change Policy: an overview of issues and options." Keio Economic Studies, 41(2): 103-132

GTAI (2009). "The Photovoltaic Industry in Germany", Bonn

GTAI (2010). "The Photovoltaic Industry in Germany - Industry Overview", Bonn

Haas R. *et al.* (2008). "Promoting electricity from renewable energy sources – lessons learned from the EU, US, and Japan", in *Competitive Electricity Markets: Design, Implementation, Performance*, Sioshansi F. (ed.), Elsevier, Amsterdam

Hall B.H. *et al.* (2001). "The NBER Patent Citation Data File: Lessons, Insights and Methodological Tools", *NBER*, Cambridge, MA

Harhoff D. *et al.* (1999). "Citation Frequency and the Value of Patented Inventions", *The Review of Economics and Statistics,* vol. 81 (3): 511–515

Harrison R., (2010). "Photovoltaic Solar Cells: Patents in Europe", 6 January, http://www.tangible-ip.com/2010/photovoltaic-solar-cells-patents-in-europe.htm

Honda J. (2009). "History of Photovoltaic Industry Development in Japan", from *Proc. of ISES Solar World Congress 2007: Solar Energy and Human Settlement* (Vol. I – Vol. V), D.Yogi Goswami & Yuwen Zhao ed., Springer, Berlin & Heidelberg: 118-123

Horn M. (2009). "Reliable Electricity from Sun and Wind", in *Fraunhofer Magazine*, n. 1-2009: 20-21

International Bureau of Fiscal Documentation (IBFD 2004). "Tax Treatment of Research and Development Expenses", Amsterdam

International Science Panel on Renewable Energies (ISPRE 2009). “Research and Development on Renewable Energies: A Global Report on Photovoltaic and Wind Energy”, Paris

Iuchi M., Konakayama A., Ohkawara T., Tsuchiya T. (1996). “An empirical analysis of consumer decision making processes on setting up residential photovoltaic systems”, CRIEPI Report Y96006, Central Research Institute of Electric Power Industry. (in Japanese)

Jacobsson S., Bergek A. (2004). “Tranforming the energy sector: the evolution of technological systems in renewable energy technology”, *Industrial and Corporate Change,* vol. 13 (5): 815-849.

Jager-Waldau A. (2009). “PV Status Report”, European Commission, DG Joint Research Centre, Institute for Energy, Renewable Energy Unit, Ispra, Italy

Kaizuka I. (2009). “Status of PV Policy and Market in Japan”, IEA PVPS Workshop, Putrajaya

Kimura O., Suzuki T. (2006). “30 years of solar energy development in Japan: co-evolution process of technology policies and the market”. 2006 *Berlin Conference on the Human Dimensions of Global Environmental Change*: “Resources policies: Effectiveness, Efficiency, and Equity”.

Klein A., Pfluger B., Held A., Ragwitz M., Resch G., Faber T. (2008). “Evaluation of different Feed-In Tariff Design Options – Best practice paper for the International Feed-in Cooperation”, BMU, October, 2nd ed.

Kreutzmann, A., Siemer, J. (2010). “Smooth Sailing: Market survey on solar modules 2010”, *Photon International*, 2-2010: 136-169

Lacey S. (2010). “Is Organic PV the Future of Solar?”, *Renewable Energy World*, May 3, 2010

Lorenzoni A., Zingale L. (2004). *Le fonti rinnovabili di energia. Un'opportunità di politica industriale per l'Italia*, Franco Angeli Editore, Milano

A. Luque, S. Hegedus, eds. (2003). *Handbook of Photovoltaic Science and Engineering*, John Wiley and Sons, Hoboken, NJ

MacKay D.J. (2009). *Sustainable Energy - without the Hot Air,* UIT Cambridge, UK

Margolis R.M., Kammen D.M. (2001). "Energy R&D and Innovation: Challenge and Opportunities for Technology and Climate Policy", in Schneider S., Rosencranz A., and J. Niles eds., *A Reader in Climate Change Policy*, Island Press, Washington, DC

Margolis R.M., Kammen D.M. (1999). "Underinvestment: The Energy Technology and Rand Policy Challenge", *Science*, vol. 285, no. 5428: 690-692

Maycock P. (2005). "Market Update: Global PV production continues to increase," *Renewable Energy World*, no. 8(4): 86-99

McWright Howerton M., Batchman T. E. (1988). "A thin-film Waveguide Photodetector Using Hydrogenated Amorphous Silicon", *Journal of Lightwave Technology*, Vol. 6, issue 12:1854-1860.

METI (2008). "Outline of the RPS System in Japan", Tokyo.

METI – by Kawabata T. (2009). "Japanese Policies Related to New and Renewable Energy & Grid Integration", Tokyo

METI (2010), Agency of Natural Resources and Energy, "Energy in Japan – Facts and Figures", Tokyo

Mills A.A., Clift R. (1992). "Reflections on the "Burning Mirrors of Archimedes'", *European Journal of Physics,* no. 13: 266

Mitre Corporation (1978). "Solar Energy: A comparative analysis to the year 2020", Technical Report MTR-7579, Virginia

Mowery D.C. *et al.* (2001). "The growth of Patenting and Licensing by US Universities: An Assessment of the Effects of the Bayh-Dole Act", *Research Policy* 30: 99-119

Mowery D., Rosenberg N. (1979). "The influence of market demand upon innovation: a critical review of some recent empirical studies", *Research Policy* 8 (2): 102-153

Mowery D., Rosenberg N. (1989). *Technology and the Pursuit of Economic Growth,* Cambridge University Press, Cambridge, UK

Nemet G.F. (2009). "Demand-pull, Technology-push, and government-led incentives for non-incremental technical change", *Research Policy* 38: 700 -709

Nemet G.F., Kammen D.M. (2007). "US energy research and development: Declining investment, increasing need, and the feasibility of expansion", *Energy Policy* 35 (1): 746-755

Neuhoff K. (2005). "Large Scale Deployment of Renewables for Electricity Generation", *Oxford Review of Economics Policy*, vol. 21 (1): 88-110

Nishio K., Asano H. (2006). "Supply amount and marginal price of renewable electricity under the renewable portfolio standard in Japan", *Energy Policy* 34 (18): 2373-2387

O'Regan B., Gratzel M. (1991). "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO2 films", *Nature*, Vol. 353, Issue 6346: 737-740

OECD/IEA (2004). Renewable Energy, Market and Policy Trends in IEA countries, OECD, Paris.

Oulton W. ed. (2009). *Investment Opportunities for a Low Carbon World*, GMB Publishing, London

Pagliaro M., Palmisano G., Ciriminna R. (2008). *Il Nuovo Fotovoltaico, dal Film Sottile alle Celle a Colorante,* Dario Flaccovio ed., Palermo

Politecnico di Milano, Dipartimento di Ingegneria Gestionale (2008). "Solar Energy Report - Il Sistema Industriale Italiano nel Business dell'Energia Solare", Technical Report, Umberto Bertelé (ed.), Milano

Powell T. (2009). "Photosynthesis", *Berkeley Science Review*, Issue 16: 16-21

Rammer C. (2007). "Monitoring and analysis of policies and public financing instruments conducive to higher levels of R&D investments - The policy mix project, Country Review Germany", United Nations University and Universiteit Maastricht

REN 21 (2009). "Renewables Global Status Report", 2009 update, Paris

Rheinisch-Westfalishes Institut fur Wirtschaftsforschung - RWI (2009). "Economic Impacts from the promotion of renewable energies: The German experience", Final Report, Essen

Rosenberg N. (1994). *Exploring the Black Box: Technology, Economics, and History*, Cambridge University Press, New York,

Savage S.L. (2009). *The Flaw of Averages: Why we Underestimate Risk in the Face of Uncertainty*, John Wiley and Sons, Hoboken, New Jersey

SEIA (2009). "US Solar Industry: Year in Review 2008", Washington D.C.

SEIA (2010). "US Solar Industry: Year in Review 2009", Washington D.C.

Shilling M.A., Esmundo M. (2009). "Technology S-curves in renewable energy alternatives: Analysis and implications for industry and government", *Energy Policy* 37: 1767-1781

Sklar S. (1990). "The role of the Federal Government in the Commercialization of Renewable Energy Technologies", *Annual Review Energy* 15:121-132

Solar & Energy Co. (2010). "Crystalline Si Solar Cell and PV Module Key Patent Analysis", South Korea

Solow R. (1956). "A contribution to the theory of economic growth", *Quarterly Journal of Economics* 70 (1): 65-94

Stryi-Hipp G. (2004). "The effects of the German Renewable Energy Sources Act (EEG) on market, technical and industrial development", German Solar Industry Association, 19th European Photovoltaic Solar Energy Conference, Paris

Tester J.W., Drake E.M., *et al.* (2005). *Sustainable energy: Choosing among options*. MIT Press, Cambridge, MA

Tomain J.R., Cudahy R.D. (2004). *Energy Law in a Nutshell*, Thomson West (2nd ed.)

VDEW (2000). Elektrizitatswirtschaft, Verband der Netzbetreiber - VDN – e. V.beim, vol. 24, Berlin,

Wadia C. (2009). "How to Bring Solar Energy to Seven Billion People", Science at the Theatre Conf., LBNL, April 6, 2009, Berkeley, CA

Wadia C., Alivisatos A.P., Kammen D.M. (2009). “Materials Availability Expands the Opportunity for Large-Scale Photovoltaics Deployment”, *Environmental Science and Technology* 43 (6): 2072-2077

Watanabe C. *et al.* (2003). “Behaviour of technology in reducing prices of innovative goods: an analysis of the governing factors of variance of PV moduel prices”, *Technovation* 23: 423-436

Watanabe C. *et al.* (2000). “Industrial dynamism and the creation of a "virtuous cycle" between R&D, market growth and price reduction: The case of photovoltaic power generation (PV) development in Japan”, *Technovation* 20 (6), June 2000: 299-312

Weiss I., Sprau P. (2002). “100,000 Roofs and 99 Pfennig: Germany’s PV Financing Schemes and the Market”, *Renewable Energy World*

Weissman S. (2009). “For renewable energy in California, it is not sure which way the wind is blowing”, www.legalplanet.wordpress.com, accessed November 2009

Wiser R., Barbose G. (2008). “Renewables Portfolio Standards in the United States. A status report with data through 2007”, Lawrence Berkeley National Laboratory, Report no. 154, Berkeley, CA (http://eetd.lbl.gov/ea/ems/re-pubs.html)

Wiser R. *et al.* (2006). “Letting the Sun Shine on Solar Costs: An Empirical Investigation of Photovoltaic Cost Trends in California”, LBNL-59282 NREL/TP-620-39300, Berkeley, CA

Wiser R. *et al.* (2007). “Renewable Portfolio Standards: A factual introduction to experience from the United States”, LBNL-62569, Berkeley, CA

Wiser R. *et al.* (2009). “Tracking the Sun II, the Installed Cost of Photovoltaics in the US from 1998-2008”, LBNL-2674E, Berkeley, CA

WEBSITES

www.energy.gov
www.energy.ca.gov
www.eia.doe.gov
www.nsf.gov
www.dsireusa.gov
www.seia.org
www.calseia.org
www.nrel.gov
www.lbl.gov
rael.berkeley.edu
www.law.berkeley.edu/clee.htm
erg.berkeley.edu
gspp.berkeley.edu
ei.haas.berkeley.edu
berc.berkeley.edu
www.solarbuzz.com
www.gosolarcalifornia.ca.gov
www.uspto.org
www.wipo.int
www.epo.org
www.stats.oecd.org
www.iea.org
www.epia.org
www.erec.org
www.bmu.de
www.bdew.de
www.ise.fraunhofer.de
www.meti.go.jp
www.jpo.go.