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Survey of Photovoltaic Industry and Policy in Germany and China*

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March 2011

Abstract

As building-integrated photovoltaic (PV) solutions can meet around one-third of electricity demand in Germany and China, both countries are interested in exploring this potential. PV technologies have demonstrated significant price reductions, but large-scale global application of PV requires further technology improvements and cost reductions along the value chain. We analyze policies in Germany and China, including deployment support, investment support for manufacturing plants and R&D support measures, and we survey the industrial actors they can encourage to pursue innovation. While deployment support has been successful, investment support for manufacturing in these nations has not been sufficiently tied to innovation incentives, and R&D support has been comparatively weak. The paper concludes with a discussion of the opportunities for global policy coordination.

Keywords: Photovoltaics, Technology Policy, Innovation, Investment Support
JEL: O31, Q42, Q48

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1 Introduction

Photovoltaic (PV) solutions could meet a major share of global power demand by direct transformation of solar energy into electricity. With current crystalline technologies, building-integrated solar cells could meet almost one third of German and Chinese electricity demand in 2020. The contribution of thin film technologies would be less because of their lower efficiencies. This shows that cell efficiencies can be relevant from a long-term energy security perspective.

However, significant cost reductions are necessary to make high penetrations of PV an economically viable option. The cost of power from photovoltaics is currently more than twice the cost of power generated from conventional sources. Because various PV components make significant contributions to total cost, improvements are necessary throughout the value chain.

As past cost reductions were delivered by research labs, equipment producers, manufacturing companies, and project development, financing and installation, we assess the current market structure at the example of manufacturing to understand the actors that can contribute to future cost reductions. While production capacities for PV manufacturing are higher in China, more of the manufacturing equipment is supplied in Germany. The level of concentration and vertical integration within industry is similar in both countries. Thus in both countries firms that are vertically integrated along the value chain have the ability to explore new technology trajectories, while segment specialists can better explore new processes and technologies within their segments.

This leads us to the support schemes and other public policy measures applied to encourage innovation in this sector. They fall in three categories: deployment support, investment support for manufacturing plants, and R&D support measures.

The demand for PV panels is driven by deployment support schemes, with the German feed-in scheme responsible for around half the global demand in 2009 and 2010. A gradual growth of demand creates continued investment in new manufacturing plants and growing markets for innovative equipment suppliers. However, the German experience highlights potential improvements. In 2009, PV module prices declined unexpectedly quickly. The resulting increase in profitability led to larger than anticipated deployment volumes. The higher than expected build out, in turn, led to concerns about the cost of the program, and points to a need for further review of policy design and adjustment mechanisms.

PV manufacturers benefit directly (and equipment suppliers indirectly) from investment support measures for PV manufacturing plants in both China and Germany. Such measures include: direct subsidies, reduced taxes, public guarantees and interest-reduced loans. An important policy question is the extent to which linking support policies to innovation requirements improves or accelerates technology development, and, if so, the extent to which such linkages would benefit from coordination on a national and international level. Currently, regional policies for supporting investments in manufacturing plants are not linked to R&D criteria in China. In Germany, innovation requirements within German investment support policies are either relatively weak or do not exist at all.

Much of the motivation for the deployment and investment support for photovoltaics is to support technology improvement. This indirect support is warranted wherever direct R&D support cannot directly target the relevant actors; does not provide appropriate incentives; and cannot facilitate feedback from the interaction between producers and users. That said, there are likely to be instances where direct R&D support could be an effective and efficient tool for achieving technology development. The values of PV R&D support schemes constitute only small shares of the value of deployment support in Germany and China. Additional opportunities for direct R&D support exist: to use R&D to explore new options / technologies; and to enhance public co-funding of private innovative / R&D activities.

2 Photovoltaics: Technical potential and cost reduction potential

2.1 Historical development of PV installations and production

The following figures show the historical development of annual PV installations and world PV cell/module production. The estimate for global production shares in Figure 2.2 is likely to be less accurate due to incomplete reporting of sales and capacity utilization of manufacturers.

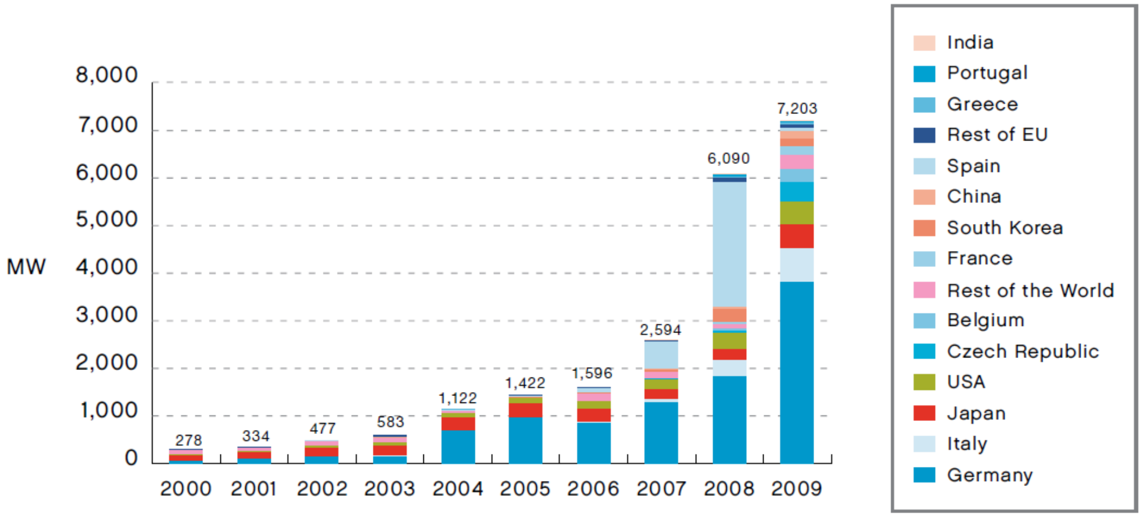

Figure 2.1: World Annual Photovoltaic Installations (EPIA 2010)

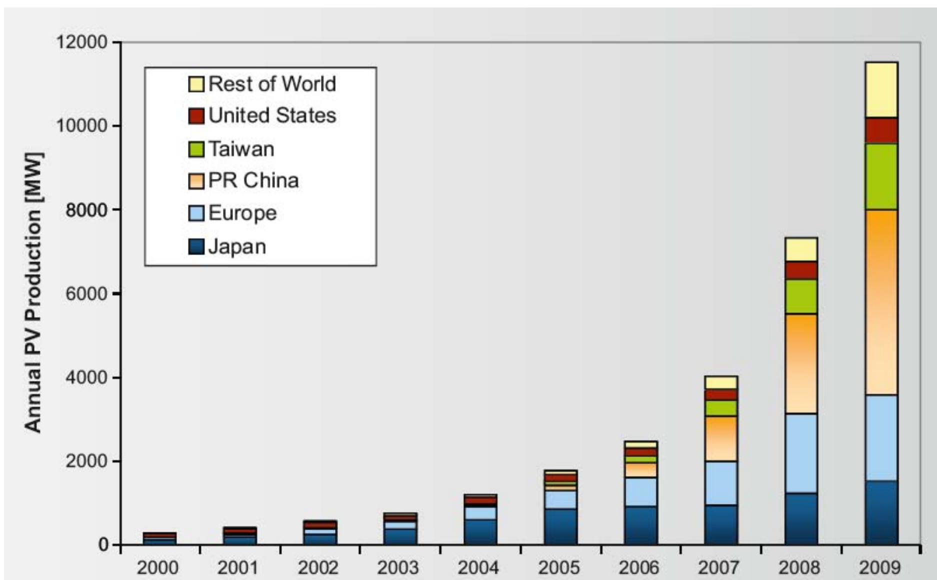

Figure 2.2: World PV Cell/Module Production (EC 2010)

2.2 Photovoltaic technologies

The global PV market is dominated by solar cells based on mono- and multi-crystalline silicon wafers. These devices currently account for 90% of PV production (Bagnall and Boreland 2008). Thin-film technologies (single-junction) are characterized by reduced costs of the active material but also by lower efficiencies (Table 2.1). Multi-junction devices are still at the demonstration level with no significant deployment volumes.

While crystalline silicon wafer-based PV has the advantages of high conversion efficiency and abundant silicon material, its drawbacks are the larger amounts of silicon required and the high costs for purification. The advantages of thin-film PV are: lower costs per watt at module level (for CdTe), lower requirement for semiconducting material, and production processes in one casting. However, the drawbacks of thin-film technologies are higher surface area requirements (due to lower efficiency), scarcity of some input materials for non-silicon based approaches (e.g. tellurium (Te)), and potential health hazards from materials such as Cadmium (Cd).

Photovoltaic technologies							[*]
Technology	**Crystalline wafer based** (single-junction solar cells based on silicon wafers)		**Thin Film** (single-junction)			**Multi-junction**	
	Monocrystal-line/ single crystal (c-Si)	Multicryst. silicon (mc-Si)	Amorphous silicon (a-Si)	Cadmium telluride (CdTe)	CI(G)S/ CuIn (Ga)Se_2		
Cell techno-logy shares (in 2007)	42,2%	45,2%	5,2%	4,7%	0,5%		[1] [2]
Cell Efficiency (at STC)	16-19%	14-15%	5-7%	8-11%	7-11%	49-51%	[2] [3]
Module Efficiency	13-17%	12-14%					
Module Efficiency** (laboratory)	22,9% ± 0,6%	15,5% ± 0,4%	10,4% ± 0,5%	10,9% ± 0,5%	13,5% ± 0,7%	55,9%	[4] [5]

** Confirmed terrestrial module efficiencies

[*] Sources: [1] Photon 2008, [2] EPIA 2008, [3] Industry interview,
[4] Green et al. 2008, [5] Green 2006 (for multi-junction)

Table 2.1: Photovoltaic technologies, with cell technology shares, cell and module efficiencies

Several ideas for new cell designs have been proposed to reduce costs or increase efficiencies, including the use of quantum wells and quantum dots to enhance absorption (Barnham and Duggan 1990); the use of impurity levels (Corkish and Green 1993); impact ionization to utilize the kinetic energy of carriers (Kolodinski et al. 1993) (Landsberg et al. 1993); and dye-sensitized cells (Gratzel 2001). However, most of these concepts have proven very difficult to demonstrate in practice.

The best-proven new technology is that based on the use of multiple junctions (Green 2006; Yoshimi et al. 2003). A stack of different solar cells with multiple bandgaps utilizes the entire solar spectrum. This technology is the current efficiency leader and is already commercially used in powering satellites (Brown and Wu 2009). For two- (tandem), three- and four-junction devices, maximum efficiencies of 55.9%, 63.8% and 68.8% are predicted (Green 2006). Due to their high production cost, multi-junction solar cells are combined with concentration optics and therefore require frames that can be adjusted to follow the direction of the sun.

2.3 Technical potential of different photovoltaic technologies

To assess the potential contribution of PV to energy supply, we compared three scenarios of PV technology development by 2020, dominated by crystalline silicon wafer-based PV, thin film and multi-junction devices respectively. Figure 2.3 shows a comparison of the future technical potential of photovoltaics in China and Germany.

The estimations of available installation areas in Germany vary between 1,000 km^2 (Nitsch 1999) and 5,178 km^2 (Kaltschmitt 2002), due to different assumptions about suitable areas, and the amount of space reserved for separate solar thermal applications. We base our calculations on the potential roof-top (864 km^2) and façade (200 km^2) areas given by Quaschning (2000), and on 1,200 km^2 of available free space areas that can be covered with PV. The potential area for PV in China includes 4,000 km^2 roof-top, 1,000 km^2 façade and 12,000 km^2 free space area (NDRC 2004, NDRC 2007), assuming that 20% of roof-tops and façades and 1% of the Chinese desert surface can be covered with PV installations (CRESP 2009).

For future module efficiencies the highest commercial efficiencies of currently available modules are assumed for each PV technology (17% for crystalline wafer-based PV, 11% for thin film PV; see Table 2.1). When combined with solar concentrators, multi-junction solar cells need two-axis tracking, and are thus not suitable for roof-top, façade and traffic areas. To allow for effective tracking of the sun, we assume that area usage is reduced by one third. German electricity consumption is expected to stay constant until 2020, while Chinese power consumption is assumed to increase by 44% (from 2007 to 2020) (YE Lei).

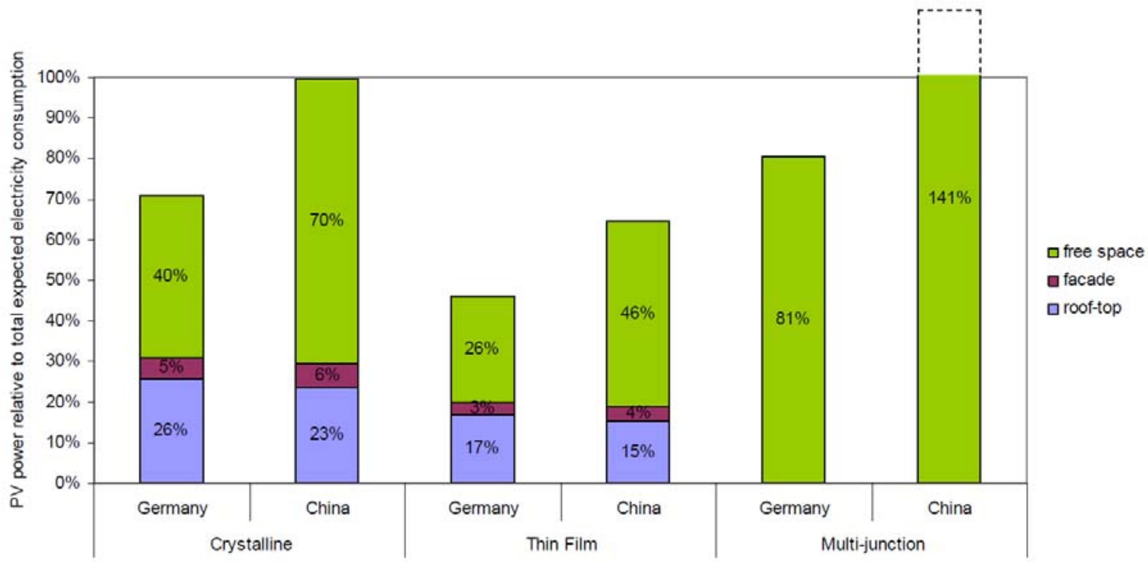

Figure 2.3: PV technical potential 2020 in Germany and China based on different technology choices

With constrained deployment area, more efficient technologies can make larger contributions to energy supply. Based on our assumptions on space availability, building integrated crystalline PV could provide 31% of power in Germany and 29% of power in China. With free space installations, these numbers increase to 71% in Germany, and around 100% in China. System requirements, in particular electricity storage, are not considered in this assessment.

2.4 Cost and price development of PV

The cost of PV has declined by a factor of nearly 100 since the 1950s (Nemet 2006). Figure 2.4 shows that despite a large increase in deployment volumes after 2003, initially price reductions were small. Unexpected demand growth, driven by rapid increase of support schemes across the globe, resulted in demand increases that exceeded production capacity, and thus created scarcity rents. The system price data in Figure 2.4 shows prices for roof-top installations. Net prices of PV applications > 100 kWp are 8% lower than prices of applications 30-100 kWp, 21% lower than prices of applications 5-10 kWp, and 42% lower than prices of applications 1-2 kWp (prices at the end of 2009, VAT excluded, according to (IEA 2010)). Large-scale applications received correspondingly lower support levels (see Table 4.1), but also do not deliver the same level of distribution savings.

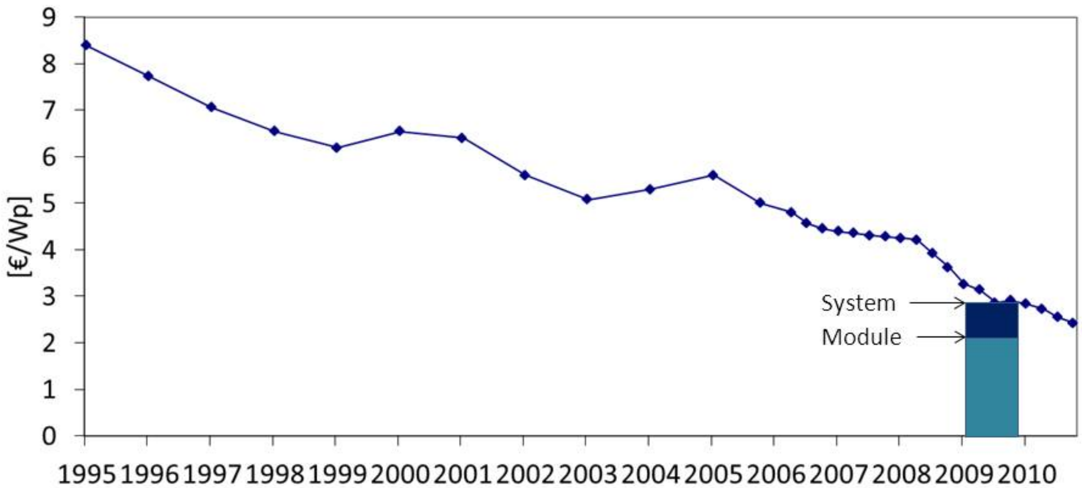

Figure 2.4: Trend in PV (roof-top) system prices in Germany

(Based on data from: (IEA 2009), (IEA 2010), (BSW-Solar 2010), (BSW-Solar 2011), (pvXchange 2010))

Figure 2.5 shows that power generation cost from photovoltaics in Germany currently exceeds the cost of power generated from coal by a factor of two. This assumes carbon prices of 30 Euro/t CO_2 and regulatory policies that allow low-cost financing. The cost reductions required for PV to become competitive depend upon the cost of alternative fuels, carbon pricing and the level of solar radiation, among other considerations.

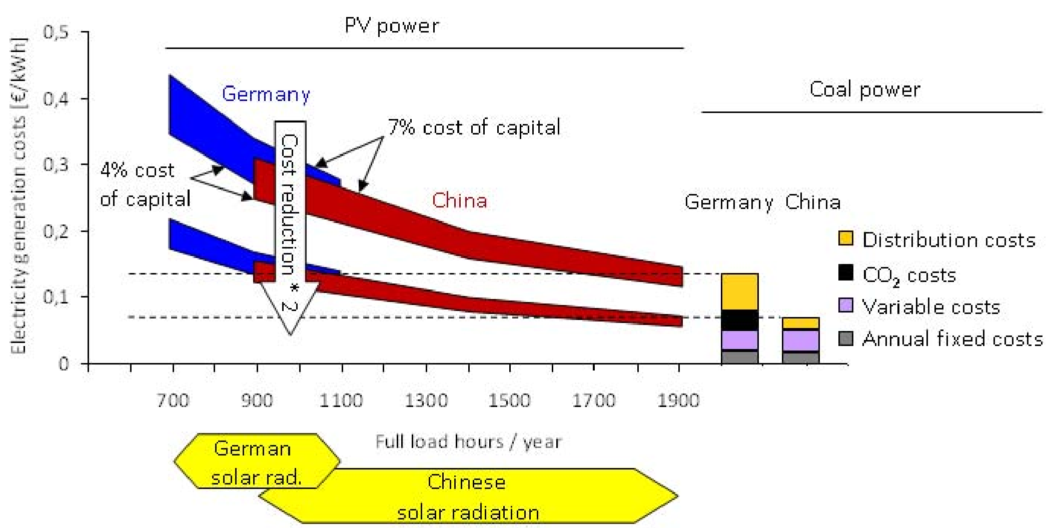

Figure 2.5: PV and coal power generation costs

The upper blue and red areas show the range of current PV power generation costs in Germany and China respectively. For this calculation, we used Chinese and German system prices (10-20 kWp) during the third quarter of 2010 (data from EuPD Research, based on system prices reported by vendors). Furthermore, we assumed an average system lifetime of 20 years and annual maintenance costs of 1%. The upper and lower boundary of each cost range is given by 4% and 7% cost of capital. The range of full load hours that PV modules can achieve per year depends upon solar radiation and varies between 700 and 1100 in Germany and between 900 and 1900 in China.

The cost of power generated from coal in Germany comprises €20/MWh cost for capital costs and annual fixed costs, fuel costs of €29/MWh (based on forward coal prices of $105/t coal for 2012, and assumed thermal efficiency of 38%), and carbon costs assuming CO_2 prices of €30/tCO_2. The initial shares of solar power reduce distribution and transmission costs, and thus do not need to be exposed to associated costs of €55/MWh. In China, coal power generation costs comprise €17/MWh annual fixed costs, €34/MWh variable (fuel) costs, and €17/MWh distribution costs. By assuming a future cost reduction factor of two, as shown in figure 2.5, photovoltaic power generation will reach large-scale competitiveness.

2.5 Photovoltaic value chain with cost reduction potentials

The (crystalline) PV production chain covers four production stages: Ingot, Wafer, Cell and Module. Their respective cost shares (of total processing costs) are given in the following table.

Supply chain	*Cost share*	*Factor*
Ingot (silicon)	17%	Ingot casting
Wafer	20%	Kerf loss
		Wafer thickness
		Wafer size
		Yield
Cell	22%	Cell efficiency
		Stability
		Lifetime
		Yield
Module	41%	

Table 2.2: Production chain with cost shares and technology improvement opportunities
(cost shares from (Deutsche Bank 2009))

To achieve future price reductions in the order of a factor of two, it does not suffice to improve costs in just one production component, but costs must be reduced throughout the value chain. Table 2.2 also identifies some technology improvement opportunities. Further cost reductions can be achieved through improvements of: the PV cell / module, the production process, the equipment used for manufacturing, as well as through scale effects, and potential localization of technology / production to countries with lower labor costs. PV costs have fallen drastically over the last fifty years. Can this downward trend be maintained so as to make PV cost competitive with existing power generation technologies?

The next section identifies the actors who might pursue the necessary technology improvements and cost reductions to reach competitiveness for photovoltaics.

3 PV industry structure – the actors who can drive cost reductions

Technology improvements and cost reductions result from individual actors' exploration of improvement opportunities and alternatives. The industry structure impacts on their incentives and ability to pursue innovative activities and is therefore characterized for China and Germany (late 2009).

3.1 Industry structure in Germany

The German photovoltaic industry includes around 70 manufacturers (of silicon, wafers, solar cells, and modules), more than 100 PV equipment manufacturers, and employs more than 57,000 people. German PV industry sales surpassed the €9.5 billion mark in 2008, while PV equipment supplier sales accounted for an additional €2.4 billion (GTAI 2009c). Figure 3.1 shows the biggest PV manufacturers in Germany, with their respective capacities in 2009, along the (crystalline) PV production chain.

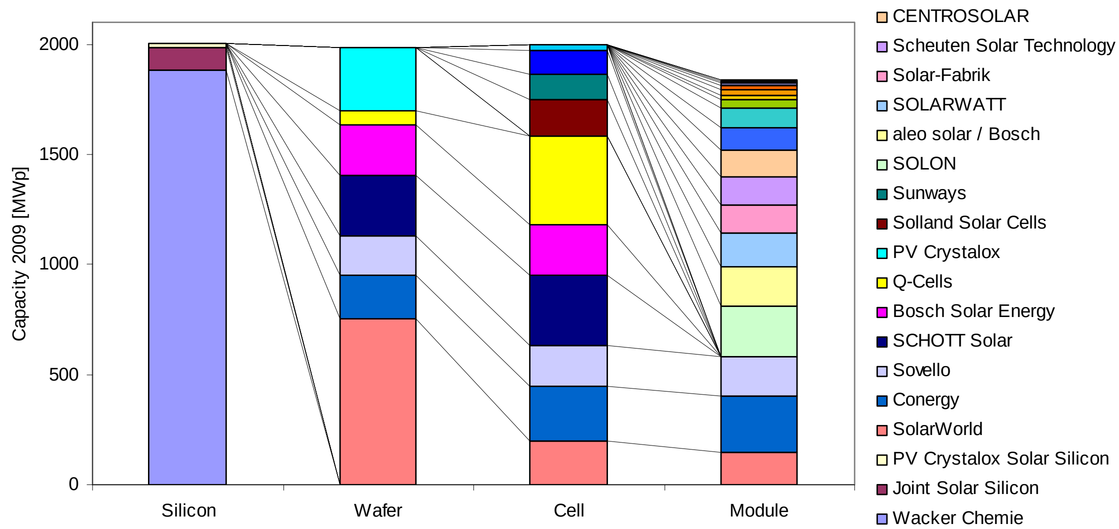

Figure 3.1: PV manufacturers in Germany along production chain

(Excluding companies active in thin film technologies, based on data from GTAI (2009a))

The number of companies in the first stage of the PV production chain (dominated by Wacker Chemie AG) is small, as polysilicon production and processing require intensive technical knowledge and substantial investment. Towards the end of the production chain, the number of manufacturers is larger, due to lower requirements for investment and knowledge-intensiveness. There are also fully integrated companies combining wafer, cell, and module manufacturing, such as SolarWorld, Conergy and Sovello.

Figure 3.2 shows PV equipment manufacturers in Germany active in different stages along the crystalline production chain, in the field of thin film technologies, as well as in the areas of automation and laser processing. While some companies offer turnkey lines for thin film devices, crystalline cells or modules, other equipment producers supply specific tools, for instance tabbers and stringers for crystalline modules.

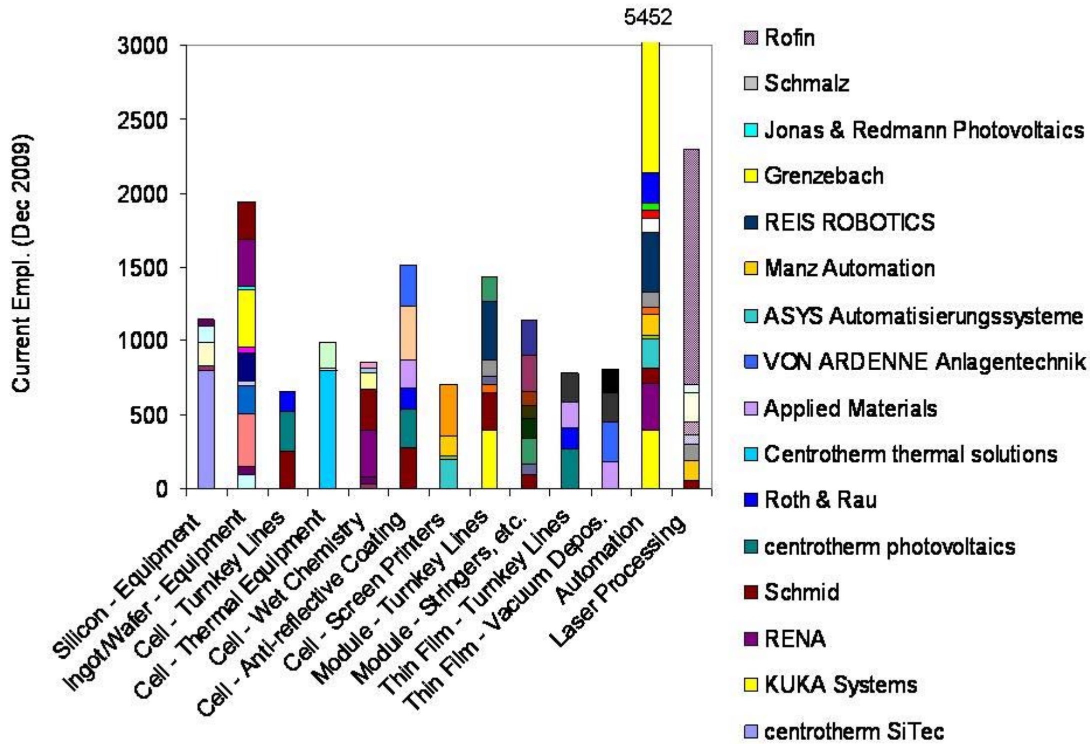

Figure 3.2: PV equipment manufacturers in Germany

(The legend shows only companies with 400+ employees, based on data from GTAI (2009b))

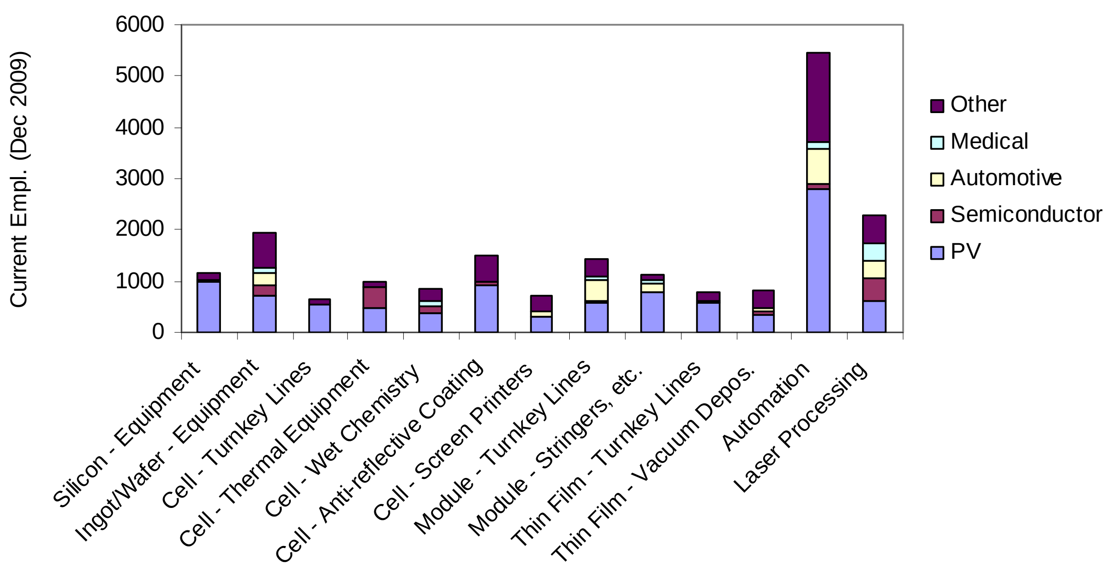

Figure 3.3: PV equipment manufacturers in Germany – sector background (activity in sectors)

(Based on data from GTAI (2009b))

Equipment suppliers that have developed their skills in supporting manufacturing of semiconductors, chemicals, optics and glass, have devoted their expertise to PV manufacturing and have been instrumental in the successful development of the German photovoltaic cluster. Figure 3.3 shows the activities of equipment manufacturers in the related semiconductor, medical, and automotive industries.

3.2 Industry structure in China

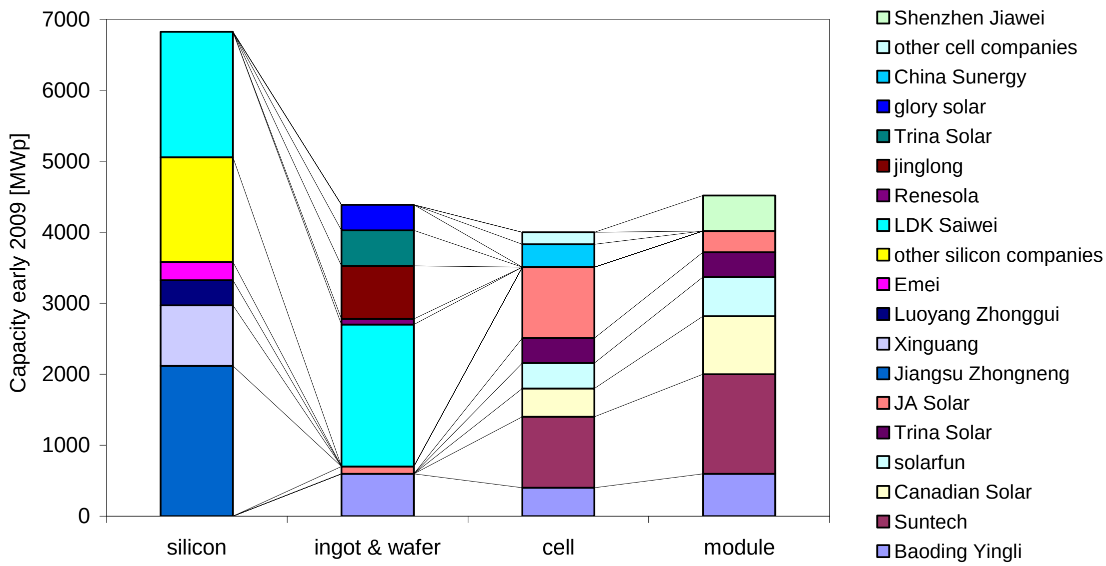

Figure 3.4: PV manufacturers in China along production chain

(Source: Company websites; CRESP; IEECAS, 2009)

In each stage of the production chain in China, we surveyed the large manufacturers who together account for more than 75% of the production (six silicon, six wafer, seven cell and seven module manufacturers, as well as other manufacturers in these categories).

Polysilicon supply did not meet demand before 2009 because it was difficult to access the necessary sophisticated technologies, which are complex and unavailable in the market. After several years' research, development and investment, Chinese R&D institutions successfully developed production technologies, and now are attracting increasing investment attention, so that the capacity in 2009 for polysilicon is higher than that of other components. Most polysilicon manufacturers were not integrated with other components because innovation capacity and intensive investment were required in the early stages of development. Now big wafer manufacturers are starting to integrate polysilicon production so as to assure material supply. The biggest integrator in China, Yingli, has integrated wafer, solar cell and module assembly since 2004, and commissioned a polysilicon facility in December 2009[4] with a production capacity of 3000 metric tons per year. The biggest wafer manufacturer in China[5] LDK, initiated a polysilicon branch and started production in January 2009.

Most wafer manufacturers were not integrated with other components before the end of 2009. In contrast with polysilicon equipment, it was always feasible to import wafer equipment, and in fact Chinese equipment manufacturers later developed their own capacity, since wafer manufacture is not as difficult a process as that of polysilicon manufacturing. Accordingly, the wafer market is very competitive. Now, big cell and polysilicon manufacturers are starting to integrate wafer production. In May 2010, a wafer facility of JA Solar broke ground in Jiangsu Province.[6] In September 2009, GCL initiated a wafer production branch in Jiangsu Province, and acquired the biggest polysilicon manufacturer in China, Jiangsu Zhongneng.[7]

Most cell manufacturing is integrated with module manufacturing. Integration allows these manufacturers to export at lower cost, compared to other non-integrated module manufacturers; moreover, their market demand is not limited by the capacity of module manufacturers. And since the process technology and equipment are easy to buy, many large cell producers have established their own module production line.

4 http://www.yinglisolar.com/about_overview.php.
5 http://www.ldksolar.com/1-16-09_cn.html.
6 http://www.js.chinanews.com/news/2010/0522/17615.html.
7 http://www.gcl-poly.com.hk/chi/products/polysilicon_facilities2.php.

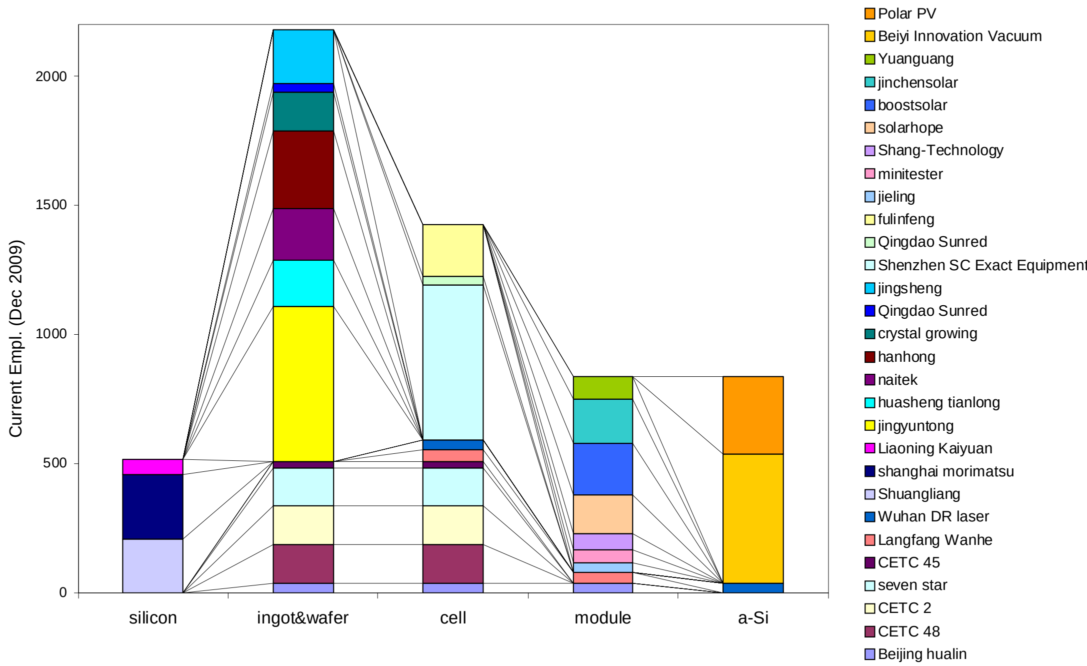

Figure 3.5: PV equipment manufacturers in China

(Source: Company websites)

We analyzed the largest equipment suppliers by their number of employees working in each segment of the production chain (Figure 3.5 covers three silicon, twelve ingot/wafer, ten cell, nine module, and three thin-film equipment suppliers). Figure 3.5 shows that the greatest integration is between equipment supply of ingot/wafer and cell equipment supply: there are five companies that integrate across these two production segments. Figure 3.5 also shows Wanhe, a supplier of cell and module equipment, and Wuhan, which offers DR laser supply for cell and a-Si.

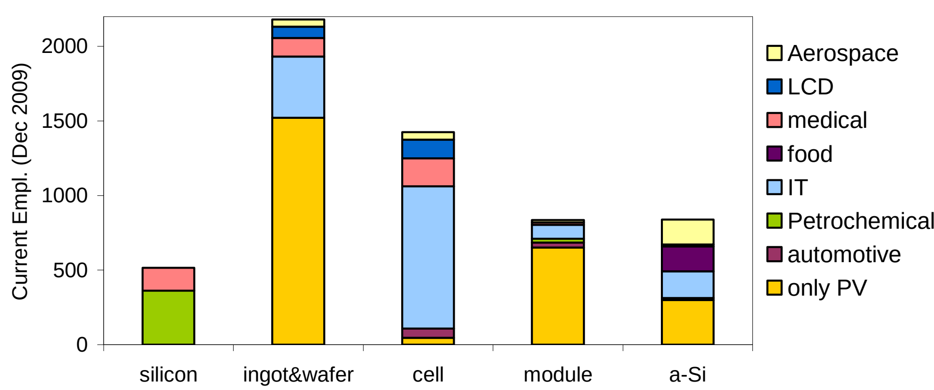

Figure 3.6: PV equipment manufacturers in China – sector background (activity in sectors)

(Source: Company websites)

Figure 3.6 shows the capacity of the PV industry, by breaking down distribution of employment by end-use industry and PV technology (module, cell, ingot & wafer, etc.). Chinese polysilicon equipment manufacturers originally produced boilers and other containers for the petrochemical and medical industries, and in recent years have moved on to researching and developing hydrogen furnaces and deoxidation furnaces for the polysilicon industry.

3.3 Summary and comparison of industries

The most notable contrast between the German and Chinese PV industries is that production capacities for PV manufacturing are higher in China, while more of the manufacturing equipment is supplied by Germany. To some extent the relative size may reflect the specific expertise of Germany and China in these two related industries, but it may also reflect the outcome of the policies in place in each country.

Beyond this difference it is noteworthy that in both Germany and China there is a mix of vertically integrated companies and value chain segment specialists. Such a mix of strategies - where some companies seek to maintain a competitive advantage in specific technologies or processes and others seek an advantage through risk management or economies of scale and scope – is not uncommon for maturing industries. Nevertheless, in an industry where policy support is so important, the mix of segment specialists and vertical integration has important implications for policy. For example, policies that increase transactions costs between segments or increase uncertainty and risk in segments of the value chain are likely to promote the integration plays, while policies that target specific segments may reinforce the segment specialists, particularly in those segments receiving support. Which of these outcomes is desirable will depend on the specific circumstances – for example, whether the sources of future cost reductions are more likely to come from de-risking of the process and growth across the value chain, or from technological advancements focused on a specific segment of the value chain.

As we aim to understand how the policy framework can explain observed innovative performance, the following sections describe these PV technology policies in Germany and China in detail.

4 PV technology policies in Germany

Since 1991, systematic governmental support schemes for PV installations have been implemented in Germany. The Electricity Feed-in Act (Stromeinspeisegesetz 1991-1999/2000) was the first policy to provide incentives for renewable electricity generation. The '1,000 Solar Roofs Initiative', which was applied between 1991 and 1995, was the first PV-specific support scheme, and was followed in 1999-2003 by the '100,000 Solar Roofs Initiative', which similarly provided loans at low interest rates for PV installations. These loans were granted by the state-owned German development bank (KfW). A feed-in tariff scheme with PV-specific support levels was established in 2000 (Renewable Energy Sources Act, EEG), and was amended in 2004 and 2009.

Figure 4.1 gives an overview of the current PV support measures applicable in Germany. Within the German strategy of fostering the deployment of renewable energy sources, the feed-in tariff scheme is the core element, supported by additional measures such as public support of R&D for PV technologies and investment support schemes for manufacturing plants.

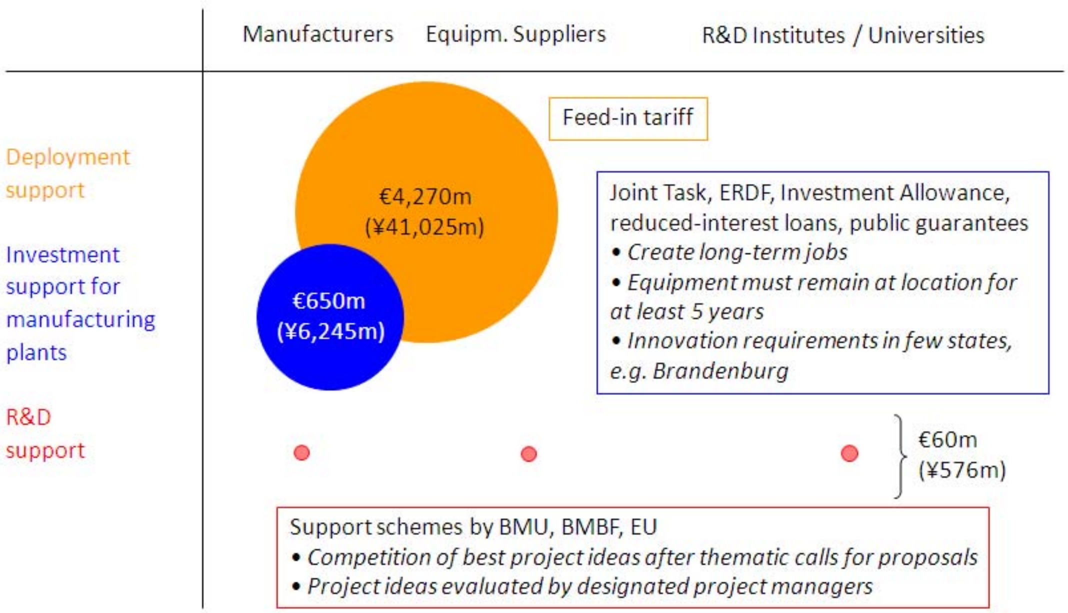

Figure 4.1: PV support measures in Germany (with main criteria) and their target groups

4.1 Deployment support in Germany

The Renewable Energy Sources Act (EEG) is applied to power generation from renewable energy sources, including wind, water, biomass, landfill-, firedamp- and biogas, as well as geothermal and solar energy. Among the supported technologies, it grants the highest feed-in tariffs to electricity produced by photovoltaic devices. These tariffs are graded according to PV system capacity (with thresholds of 30 kW, 100 kW and 1000 kW) and installation types (roof-top and field installations). The feed-in tariffs are paid for a time period of 20 years. Table 4.1 gives an overview of the recent German PV feed-in tariffs.

		Roof-top installations (€ct/kWh)				Field installations (€ct/kWh)
System size		≤ 30 kW	≤ 100 kW	≤ 1000 kW	> 1000 kW	All sizes
Date of installation	From 01.01.2009	43.01	40.91	39.58	33.00	31.94
	From 01.01.2010	39.14	37.23	35.23	29.37	28.43
	From 01.07.2010	34.05	32.39	30.65	25.55	0.00-26.15
	From 01.10.2010	33.03	31.42	29.73	24.79	0.00-25.37
	From 01.01.2011	28.74	27.33	25.86	21.56	0.00-22.07

Table 4.1: PV feed-in tariffs according to German EEG[8]

At the beginning of 2010, the tariffs saw a reduction of 11% and 9% (for roof-top installations ≤ 100 kW) respectively, in comparison to 2009 levels. However, as system prices fell much faster in 2009 than originally expected, the German government has decided to cut back the feed-in tariff further in July 2010 and October 2010, as shown in Table 4.1. The feed-in tariff for ground-mounted systems on agricultural fields was stopped in July 2010 (IEA 2010).

Between 2003 and 2009, the present value of the PV feed-in tariff subsidy in Germany amounted to €4,270 million[9] per year on average. The number of new PV installations increased significantly in 2004 and 2009 (see Figure 2.1), after the PV feed-in tariff was raised in 2004, and after system prices dropped in 2009. The total system expenditure for PV installations represented this development in the respective periods, as shown in Figure 4.2.

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[8] Sources: (EEG 2008), (BMU 2010b), (BNetzA 2010b).

[9] Calculation based on time period of 20 years, 7% discount, and based on data from the following sources: (BSW-Solar 2010), (BNetzA 2010a), (IEA 2010), (GTAI 2010e), (EEG 2008), Nomura, Point Carbon, Barclays, ECX, EEX and www.pv-ertraege.de.

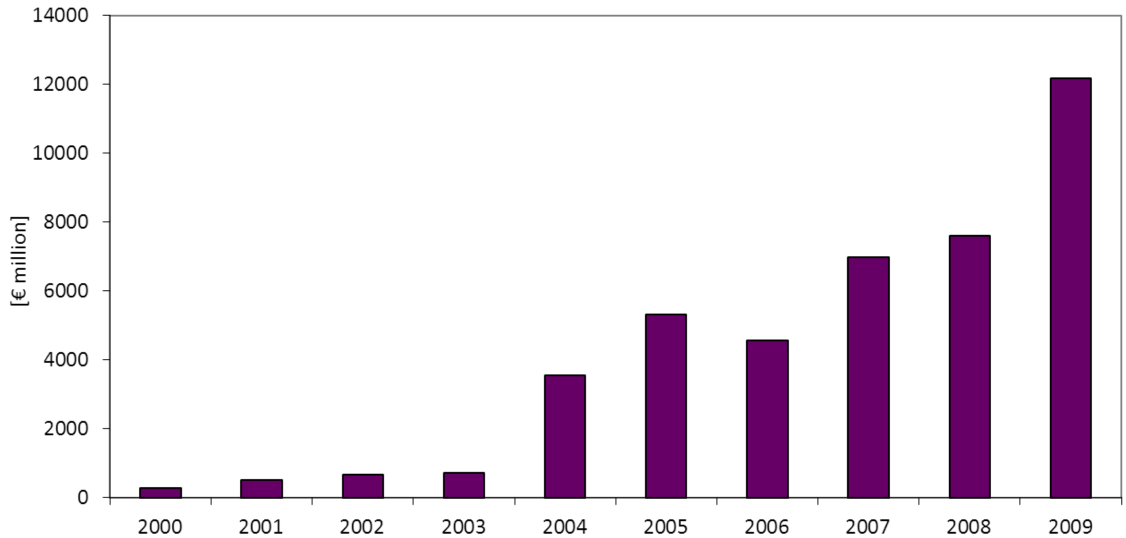

Figure 4.2: Total system expenditure for PV installations in Germany[10]

Additional national market stimulation schemes are provided by the state-owned German development bank (KfW) through the following loan programs for PV investments (IEA 2009):

- "Erneuerbare Energien Standard": Loans for private PV investments;
- "Kommunal investieren": Loans for PV investments by communities and their enterprises;
- "KfW – Kommunalkredit": Loans for investment in the infrastructure of communities to save energy and change to renewable energies.

4.2 Investment support for manufacturing plants in Germany

Germany offers different investment incentive programs which can be grouped into three packages:

- grants / cash incentives (including the Joint Task program and the Investment Allowance program);
- reduced-interest loans (at national and state level); and
- public guarantees (at state and combined state/federal level).

The same conditions apply to German and foreign investors. Funding is provided by the German federal government, the European Union (EU), and the individual federal states of Germany. The EU provides the legal and financial framework for public funding in all EU Member States.

Eligible industries, forms of investment and general program requirements are defined by each incentive program. Specific criteria within each program determine individual investment project incentive rates.

[10] Based on data from the following sources: (IEA 2010), (BSW-Solar 2010).

The highest incentive levels are usually offered to small and medium-sized enterprises (SMEs). In the following sections, we will focus on incentive levels for large enterprises[11].

a) Grants / Cash Incentives

There are two major programs offered in Germany to direct the allocation of cash incentives: the Joint Task program; and, in Eastern Germany, the Investment Allowance program. These programs reimburse direct investment costs during the investment phase of projects (before operations have started).

Joint Task Cash Grants – Gemeinschaftsaufgabe "Verbesserung der regionalen Wirtschaftsstruktur" (GRW)

The distribution of non-repayable grants (usually in the form of cash payments) for investment costs is regulated by the Joint Task program throughout Germany. The amount granted varies between different regions according to their level of economic development. The regions with the highest incentive levels (period 2007-2013) are clustered in the eastern parts of Germany – they offer grants of e.g. up to 30 percent of eligible project costs for large enterprises. In various regions in Western Germany (except the states of Baden-Württemberg and Hamburg), companies can also receive subsidy rates – for example up to 15 percent of eligible expenditures for large companies. Individual ceilings can be determined by each state, up to the maximum incentive levels, as given by the Joint Task program. Joint Task grants must be applied for before the beginning of the investment project.

The general terms and conditions of the Joint Task program and the Investment Allowance program (see next section) are shown below in Table 4.2.

[11] The following criteria specify the size of large enterprises in the European Union: (1.) staff headcount ≥ 250 and (2.) annual turnover > €50m or annual balance sheet total > €43m.

	Joint Task	Investment Allowance
Eligible industries	• Most manufacturing industries • Most service industries	• Most manufacturing industries • Certain service industries
Eligible project costs	(Direct) investment costs • Expenditures for buildings, machinery, and equipment OR (Future) operating costs • Wage costs for two years	Expenditures for buildings, machinery, and equipment
Maximum eligible investment amount	Up to €500,000 per job created (not exceeding the maximum total investment costs)	No limits set
General program requirements	• The investment project must create long-term jobs • The subsidized equipment must remain at the investment location for at least five years	• The subsidized equipment must remain at the investment location for at least five years

Table 4.2: Terms and conditions of Joint Task and Investment Allowance programs
(Source: Germany Trade & Invest)

The following figure shows that public support is effective in shaping investment choices. On the one hand, most PV equipment suppliers are located in Southern Germany. This is because many of them have strong activities in (and often originate from) highly developed related supporting industries (see Figure 3.3), which have been concentrated in the southern parts of Germany over the last decades. On the other hand, the relatively young PV manufacturers have in recent years focused their investments on new manufacturing plants in Eastern Germany, due to the investment incentive programs.

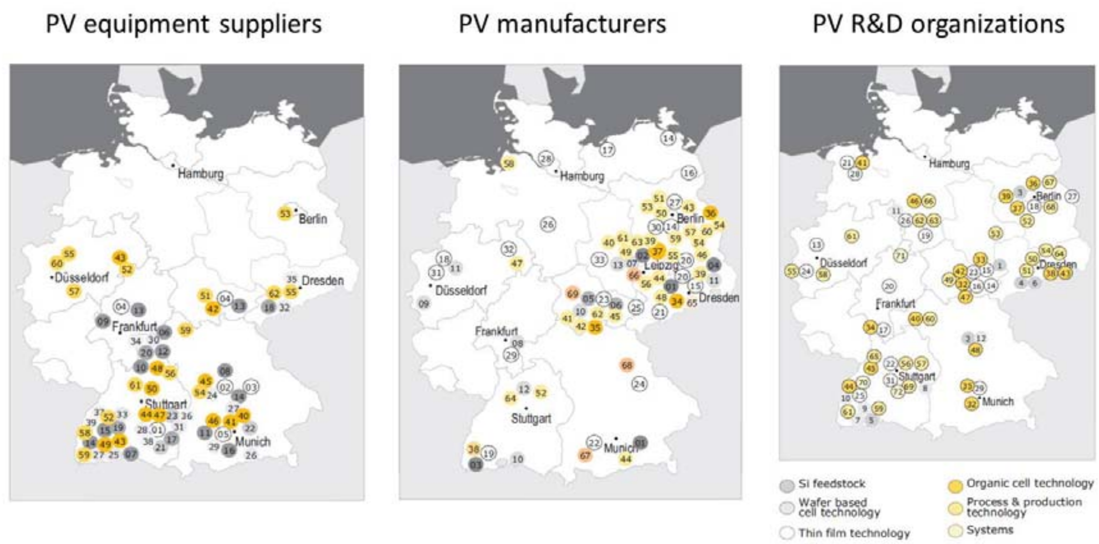

Figure 4.3: Geography of PV manufacturers, equipment suppliers, and R&D organizations in Germany
(Sources: GTAI 2010a, GTAI 2010b, GTAI 2010c)

Investment Allowance (in Eastern Germany) ("Investitionszulage")

The Investment Allowance program was created in order to promote investment projects in the new federal states of Germany (Berlin, Brandenburg, Mecklenburg-Vorpommern, Saxony, Saxony-Anhalt and Thuringia). It is based on the Investment Allowance Act 2010 (Investitionszulagengesetz). The Investment Allowance is usually allotted in the form of a tax-free cash payment. The following table shows the Investment Allowance promotion rates for large enterprises in 2009 – 2013. The respective promotion rate applicable at the start date of the project will be received by the investor for the duration of the complete project. When investing in Eastern Germany, Investment Allowance funding is automatically received (if all eligibility criteria are satisfied) without any application procedures.

Start in	2009	2010	2011	2012	2013
Investment: Machinery, Equipment; Buildings / Construction	12.5%	10.0%	7.5%	5.0%	2.5%

Table 4.3: Investment Allowance promotion rates for large enterprises
(Source: InvZulG 2010)

The Investment Allowance can also be combined with grants received under the Joint Task program. However, the maximum possible Joint Task incentives level may not be exceeded. In the exemplary case of a large company investing €100 million in the year 2010 in a region with the maximum possible Joint Task incentives level (30 percent), 10 percent will be received from the Investment Allowance (automatically) and 20 percent from Joint Task funding (application necessary).

According to BSW-Solar (2010), €2,183 million have been invested by the German PV industry in the construction, expansion and modernization of solar production factories in 2008. According to Figure 4.3 (manufacturers map), most of these investments have been realized in Eastern Germany. If we use an average incentive level of 30 percent of eligible project costs, then around €650 million have been provided as public investment support for solar manufacturing plants in Germany in 2008.

b) Reduced-Interest Loans

Publicly owned banks at the national and state level (so-called development banks) offer publicly subsidized loan programs to investors in Germany. Usually, these loan programs combine interest rates at levels below current market rates with attractive grace periods. Reduced-interest loans as a subsidy can normally be combined with other public funding programs.

KfW Loans

The KfW Banking Group (Kreditanstalt für Wiederaufbau) is the German development bank at the national level. The KfW Mittelstandsbank, which is a subdivision of the Banking Group, offers different loan programs for investment project financing. The most prominent of these loans will be described below. Investors usually contact the KfW via their normal bank with regard to the application procedure.

KfW-Unternehmerkredit (Entrepreneur Loan): The KfW Entrepreneur Loan is available to domestic and foreign commercial enterprises that are mainly privately owned (group turnover must not exceed €500 million), start-ups and self-employed professionals. The maximum amount of this loan is €10 million and the financing share is 100% of the investments or working capital eligible for financing. Small and medium-sized enterprises (according to the criteria of the European Commission) can apply for loans at additionally reduced interest rates. The Entrepreneur Loan is granted at a risk-adjusted customer-specific interest rate up to the maximum value of the respective price category, which depends upon the borrower's credit rating and the quality of collateral. Nine different price categories exist, with maximum nominal interest rates ranging between 1.90% and 8.45% for large enterprises and between 1.20% and 8.35% for SMEs. These interest rates are fixed for up to 10 or 20 years. The program offers a repayment-free start-up period, prepayment at no extra charge and 50% liability exemption. The Entrepreneur Loan (without liability exemption) may be combined with public promotional funds and other KfW programs.

KfW Sonderprogramm (Special Program): The KfW Special Program builded on the KfW Entrepreneur Loan. It was implemented to support companies overcoming their financial challenges resulting from the economic crisis, and expired at the end of 2010. The maximum amount was €50 million per project, for small and medium-sized enterprises (and €300 million per group of companies, for large enterprises).

State Development Bank Loans

Each German state has its own development bank which finances investment projects with reduced-interest loans. These loan programs are largely targeted to meet the requirements of start-ups and smaller companies. The state development banks are contacted via the applicant's own bank.

c) Public Guarantees

In order to facilitate financing investment projects of young and innovative businesses through the capital market, companies lacking securities may apply for public guarantees. The following table gives an overview of the different public guarantees available to secure bank loans in Germany.

<table>
<tr><th colspan="3">Types and Conditions of Public Guarantees</th></tr>
<tr><th></th><th>Individual State Governments</th><th>State Governments and Federal Government in Combination</th></tr>
<tr><td rowspan="2">General Conditions</td><td>Available throughout Germany</td><td>Available in Eastern Germany and in parts of Berlin</td></tr>
<tr><td colspan="2">Companies which do not have the securities demanded by the bank can apply for public guarantees.</td></tr>
<tr><td rowspan="2">Amount</td><td>For guarantee needs up to €10 million</td><td>For guarantee needs over €10 million</td></tr>
<tr><td colspan="2">Guarantee covers up to 80% of the loan amount.</td></tr>
<tr><td>Application Process</td><td>• Before starting investment, application must be submitted to state mandatory (normally the respective state development bank) via investor's commercial bank.
• State guarantee committee deliberates on application and submits a recommendation.
• Finally, state Minister of Finance decides on allocation.</td><td>• Before starting investment, application has to be submitted to PWC as federal mandatory via investor's commercial bank.
• Guarantee committee level fits close analysis on application.
• Finally, approval is given by the federal authorities in co-operation with the respective state.
• Concurrent EU authority notification necessary.</td></tr>
</table>

Table 4.4: Types and Conditions of Public Guarantees in Germany

(Source: GTAI 2010d)

4.3 R&D support in Germany

Responsibility for renewable energies within the German Federal Government belongs to the Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU). Research and development on different aspects of PV is supported by the BMU, as well as the BMBF (Federal Ministry of Education and Research). While BMBF support for PV R&D projects amounted to €19.5 million in 2008 (8 co-operative R&D projects were granted), the BMU's R&D budget for PV totaled €39.9 million, shared between 130 projects (IEA 2009). In comparison to these public PV R&D budgets, industrial R&D investments amounted to €163 million in 2008 (BSW-Solar 2010).

Within the BMU funding activities, selection criteria for PV research projects are (BMU 2010a):

- industry participation and networking structure, with preference given to collaborative projects;
- development risk and implementation time; and
- the possibility to disseminate research findings, while considering the protection of findings through patents.

Table 4.5 shows the distribution of the BMU funding. While wafer-based silicon technologies received more than half of total funding, around one-fifth was allocated to thin-film technologies. Support is also provided for alternative concepts such as concentrating photovoltaics.

Silicon wafer technology	52%
Silicon thin-film technology	10%
CIS thin-film technology	11%
Alternative PV / Absorber technologies	5%
Concentrating PV	12%
Systems engineering / Grid integration	7%
Comprehensive projects	3%

Table 4.5: Newly approved PV funding from BMU (Source: BMU 2010a)

In 2008, the BMBF set up networks aiming for the development of thin-film PV cells with a focus on topics such as material sciences and the use of synergies with other research fields, such as microelectronics. Meanwhile, the development of organic PV cells is being addressed by a joint initiative with the industry.

As part of the Federal High-Tech Strategy, BMBF also supports the development of the "Solarvalley Mitteldeutschland" cluster, which covers most of the German PV industry.

Within the initiative "Innovationsallianz Photovoltaik," which was announced in 2010, BMU and BMBF will provide €100 million for new R&D projects during the next four years. The focus of this initiative is on improving production costs and efficiencies of photovoltaics.

5 PV technology policies in China

In 2009, China's central government issued a series of PV market policies including the Golden Sun program and some large-scale on-grid feed-in tariff (FIT) projects. This market policy was aimed at the "Middle and long term program of renewable energy development," created by the National Development and Reform Commission (NDRC) in 2007, targeting solar installation at 300 MWp by 2010 and 1.8 GWp by 2020. The experience and outcome of these policies is an important reference for future market policies. Also in 2009, some city governments started offering investment incentives to encourage manufacturing investment and developed regional market policies for PV installation. We surveyed both policies applied in 2009 and those policies to be applied in 2010 which have been announced so far. In the graph below, we show the expenditure scale of each policy. Euro prices were based on the exchange rate on July 1, 2009 (¥1 = €0.10). R&D incentives have the smallest budget at both federal and regional levels.

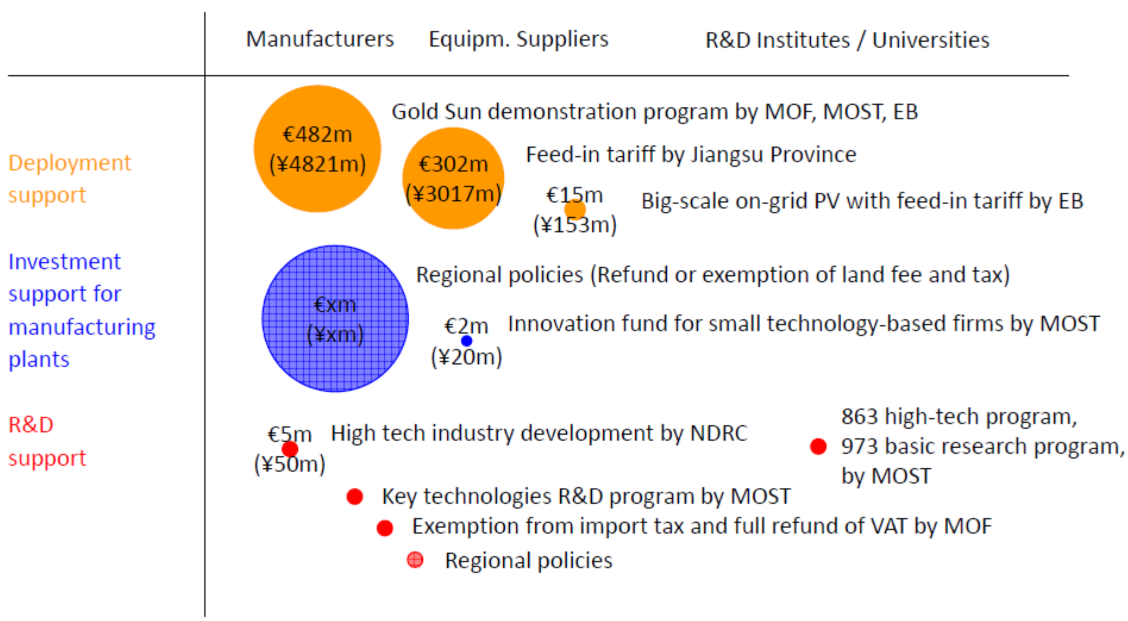

Figure 5.1: PV support measures in China in 2009

5.1 Deployment support in China

Installation investors can enjoy incentives from only one market deployment policy. We describe market policies applied in 2009 and policies applied in 2010 (to date).

a) Golden Sun program by MOF, MOST, NEA

The Chinese Ministry of Finance (MOF), the Ministry of Science and Technology (MOST) and the National Energy Administration (NEA) initiated the Golden Sun program for 2009-2011. The target of this program is to install more than 500 MW PV modules and to support demonstration of key technologies in the PV industry. To date, 294 projects of 642 MW have been approved. We calculated total public expenditure for this program at ¥4,820.92 million.

Program categories

290 MW in commercial buildings	Non-repayable cash, equal to 50% of investment
46 MW in remote rural residential buildings	Non-repayable cash, equal to 70% of investment
306 MW of large-scale on-grid PV	Non-repayable cash, equal to 50% of investment

How are applicants judged?

Provincial governments select investors and projects and submit recommendations to central government, which then makes the final decision. The federal government requires that all equipment for the Golden Sun program be purchased though competitive tender.

In September, 2010, the MOF, the MOST, the MOHURD, and the NEA announced a revision to the Golden Sun Program and the Solar Roofs Program. It stipulated that the two programs should meet the new requirements below:

- the Silicon PV module, inverter and lead-acid battery are chosen by public bidding organized by the MOF, the MOST, the MOHURD and the NEA. The public bidding chooses manufacturers, products and price; and
- the two programs support on-grid and distributed PV in cities and off-grid PV in remote rural areas. They will no longer support large-scale PV farms.

When investors purchase silicon PV modules, inverters and lead-acid batteries from manufacturers' tenders at the price bid, 50% of the cost is subsidized for distributed and on-grid PV in cities and 70% for off-grid PV in remote rural areas. In addition, a ¥4/Wp subsidy is provided for distributed and on-grid PV (¥6/Wp for BIPV) and a ¥10/Wp subsidy for off-grid PV in remote rural areas (¥6/Wp for residential PV system). PV generation can be utilized by the generator itself, or be purchased by grid companies on a regional tariff for desulfurizing coal generation.

b) The Solar Roofs Program by MOF

In 2009 for 91MW of installations (111 projects), this program supplies a maximum ¥20/Wp for building material integrated PV and a maximum ¥15/Wp for rooftop- and facade-installed PV. For applications from April to May, 2010, this program supplies a maximum ¥17/Wp for building material integrated PV and a maximum ¥13/Wp for rooftop- and facade-installed PV.

c) Large-scale on-grid PV projects with feed-in-tariff, by NEA

The National Energy Administration (NEA) has initiated large-scale on-grid PV projects by using a fixed feed-in tariff. The feed-in-tariff is decided according to bidding or FIT projects existing nearby. In 2008, a 1 MW project in Shanghai's Chongming Island and a 255 kW project in Eerduosi city, Inner Mongolia, were initiated. Two projects in Dunhuang city, Gansu province, started power generation in 2009; each project was 10MW. In June 2010, the NEA announced an invitation to tender for 280 MW of large-scale on-grid PV projects, which would run under a fixed feed-in tariff.[12]

As an example of the approach, one of the Dunhuang projects has a period of operation with a feed-in tariff of 25 years. The investor was chosen through public bidding, according to technical planning criteria and lowest feed-in tariff bid.

Using the same methodology we used to calculate public expenditure of Germany's feed-in tariff, we have calculated total alternative public expenditure on 20 MW on-grid PV projects in Dunhuang over 25 years. The Dunhuang government has confirmed[13] that annual power generation is 15,299,800 kWh, and the feed-in tariff is ¥1.09/kWh for 25 years. We assume that the discount rate is 8% (nominal discount rate), which is almost same as the social discount rate in China. Thus, the present value of total alternative public expenditure in 25 years for 20MW is ¥153.2 million (constant=2009).

The announcement in June 2010 by the NEA of a further invitation to tender for 280 MW large-scale on-grid PV projects included 60 MW in Inner Mongolia, 60 MW in Xinjiang, 60 MW in Gansu, 50 MW in Qinghai, 30 MW in Ningxia and 20 MW in Shanxi.

d) Regional deployment support policies

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12 http://www.yicai.com/news/2010/06/364998.html.
13 http://www.gspc.gov.cn/xxgk/ShowArticle.asp?ArticleID=4093.

The Development and Reform Commission of Jiangsu Province ([Jiangsu, 2009]) has issued installation planning and PV feed-in tariff policies. The planning of on-grid new installation is 80 MW in 2009, 150 MW in 2010 and 170 MW in 2011. In total, installation will be more than 400 MW by 2011. In 2009, 80MW installation was planned for rooftops. The feed-in tariff is fixed for 25 years but the level for successive years decreases to prompt cost reductions. The feed-in tariff shown below is inclusive of Value Added Tax.

(¥/kWh)	2009	2010	2011
Ground	2.15	1.7	1.4
Rooftop	3.7	3	2.4
Building integrated	4.3	3.5	2.9

We used the same methodology as above to calculate total alternative public expenditure of the feed-in tariff for 80 MW rooftop PV projects in Jiangsu province in 25 years. According to the solar resource survey of the China Meteorological Administration, north Jiangsu province is in the fourth-best solar area in China and south Jiangsu province is in the fifth-best solar area in China (concerning solar radiation intensity). Using the average solar radiation of 5000 MJ/m^2 / year and assuming a discount rate of 8%, the present value of total alternative public expenditure in 25 years is ¥3017.4 million (constant=2009).

e) Summing up

As a result of market incentives, the annual installation in 2009 was much higher than that in 2008, as shown in figure 5.2. Annual installation for 2010 is likely to keep increasing following the June 2010 announcement by the National Energy Administration to provide 280 MW large-scale on-grid PV projects with a fixed feed-in tariff; meanwhile, in 2009, Jiangsu province announced the planning of 150 MW of new installed capacity in 2010.

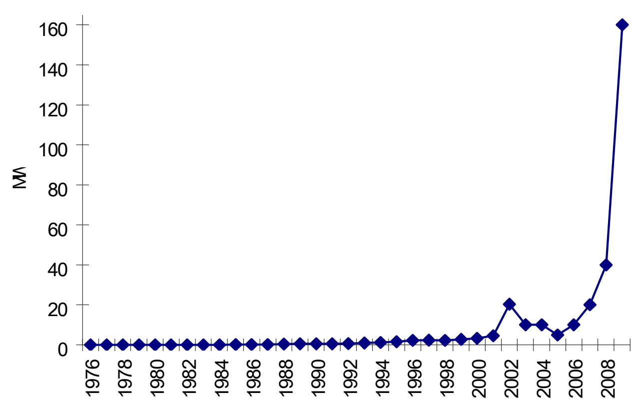

Figure 5.2: Annual installation in China

(Source: Sicheng Wang, Energy Research Institute National Development and Reform Commission)

5.2 *Investment support for manufacturing plants in China*

a) MOST innovation fund for small technology-based firms

The People's Republic of China's Ministry of Science and Technology (MOST) program was created in 1999 (MOST 1999), with the aim of supporting deployment and innovation by high-tech small firms. According to MOST,[14] the program provided about ¥20 million to support PV projects in 2009.

MOST program elements (2009)

	Specific Requirements	
1.Project for small high-tech start-ups	Less than three years old; no more than 300 employees	non-repayable cash; ¥200, 000 ～ ¥400,000
2. R&D and demonstration project for general high-tech small firms.	no more than 300 employees; the project is less than ¥10 million and firm invests more than 50%; the project results in a production line from independent R&D.	non-repayable cash; no more than ¥1m
3. Demonstration and deployment project for general high-tech small firms.	The firm has a loan from banks; no more than 500 employees; the project is less than ¥30 million.	non-repayable subsidized interest on the loan; no more than ¥1m
4. Deployment project for high-tech small firms in significant industries appointed by federal government.	Growth rate of revenue no less than 150% in three years; no more than 500 employees;	non-repayable cash; ¥1～ 2 m

Applicants meeting the following qualification criteria can apply for funding:

- this program supports independent R&D, in which the applicant owns the required know-how;
- the applicant's R&D is market-oriented, so it is likely to result in economic and social benefits;
- employees who had education beyond college level must account for at least 30% of total employees;
- the total number of R&D employees must be at least 10% of staff; and

14 http://www.most.gov.cn/bszn/new/cxjj/jgcx/200912/t20091229_75000.htm.

- annual R&D investment of the applicant must be at least 5% of annual revenue.

The selection procedure works as follows. MOST establishes the selection criteria and appoints a consulting pool – composed of academic experts and entrepreneurs – to evaluate applications. The consulting pool provides evaluation results, comments, and recommendations for receipt of funds. MOST and MOF review the results and make the final decisions. All of the funding recipients are publicized, in order to ensure transparency and offer the chance for the public to monitor the program. Eighty percent of funds to PV recipients in 2009 were provided for developing new PV products, not developing new equipment.

Some of the selection criteria are as follows:

- future market;
- technical innovation;
- technical feasibility;
- risk;
- benefits;
- operation and management of the firm.

b) Regional investment support policies

In 2009, some Chinese city governments issued various refund policies to promote new plant investment in PV industry. These were financed by the city government and city councils, and the specific criteria applied in the policies might be different in each city. However, since the policies of Huaian city, Jiangsu Province (Huaian, 2009), and Jinzhou city, Liaoning Province (Jinzhou, 2009), cover most categories and have comparatively large budgets, we use them as examples.

1) Refund of loan interest

In Huaian, if the initial investment in a new PV plant – including polysilicon, wafer, cell, module, and equipment – is more than €50 million, the new plant will receive a refund equal to 50% of the real interest of loans only in the year when most equipment was bought. In Jinzhou, any new PV plant before 2012 will get a refund equal to 100% of the interest of loans, calculated according to the national basic interest rate in that period.

2) Refund of electricity consumption fees

In Huaian, if the capacity of a polysilicon or wafer manufacturer is more than 1000 tonnes per year, the new plant will get a refund equal to ¥0.05/kWh only in the first year of production. If the capacity of cell or module manufacturer is more than 100 MW per year, the new plant will get a refund equal to ¥0.1/kWh in the first year of production.

3) Refund of land transfer fee

In Huaian, if the initial investment in PV manufacturing – including polysilicon, wafer, cell, module and equipment – is more than €50 million, the new plant could get a refund of the residual land transfer fee, after the central and provincial government collect a certain amount. In Jinzhou, any new PV plant can also benefit from this kind of refund.

4) Refund of corporate income tax

In Huaian, polysilicon, wafer, cell, module and equipment manufacturers can receive a partial refund of the residual corporate income tax, after the central government and provincial government collect a certain amount. The new plant is refunded 100% of residual corporate income tax from the first year to the second year, and 50% of residual corporate income tax from the third year to the eighth year.

5) Refund of value added tax payment

In Huaian, any new PV plant can receive a partial refund of the residual value added tax payment (VAT payment = output VAT – input VAT) after the central government and provincial government collect a certain amount. The new plant receives 50% of the residual VAT payment from the first year to the second year, and 25% of the residual VAT payment from the third year to the fifth year. In Jinzhou, this sort of incentive is also offered to any new PV plant. New plants receive 100% of the residual VAT payment from the first year to the third year, and 50% of the residual VAT from the fourth year to the sixth year.

6) Loan guarantees

Neither the Huaian nor Jinzhou governments has any policy of loan guarantees for new PV plants. Loan guarantees can be created through public-private bilateral negotiation. For example, in 2005, Jiangxi International Trust and Investment Corporation supplied ¥100 million to LDK, guaranteed by Xinyu City government (Deng Qiuyan).

We calculated the amount of subsidy available to a new plant in Huaian, when initial investment is €100 million. This benchmark scenario is based on the assumption below, and we conducted a sensitivity analysis of uncertain factors with these assumptions.

Initial investment per MW	0.5	€ million /MW
Electricity consumption per kW	1900	kWh/kW
Profit margin	10%	
Material expenditure per kW	280	€/kW

As figure 5.3 below shows, we calculated a subsidy of around 19%, which was relatively sensitive to the initial investment per MW and the price of each a-Si module. And as figure 5.4 shows, the refund of corporate income tax is the largest part of the subsidy, while the refund of VAT payment is the second largest.

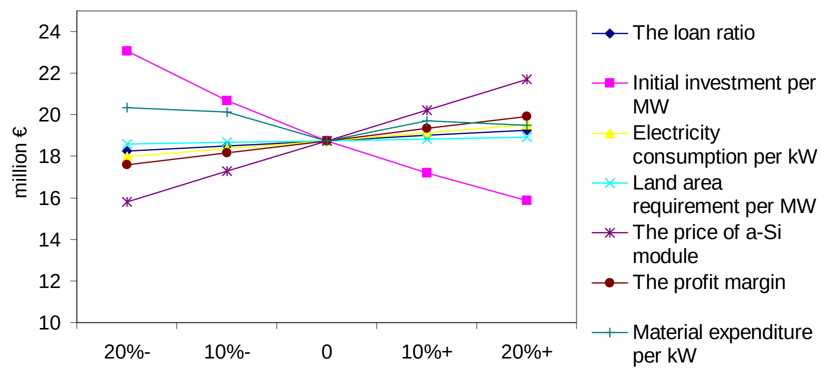

Figure 5.3: Sensitivity analysis of regional subsidies

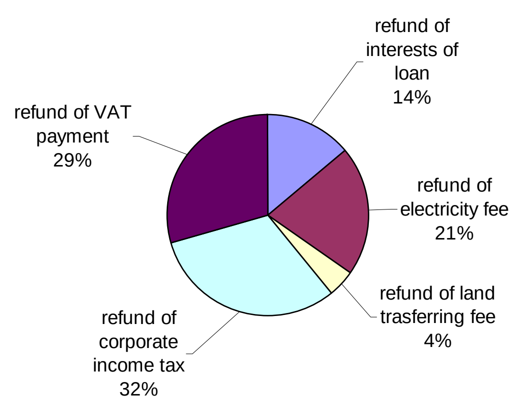

Figure 5.4: The structure of regional subsidies

c) Loan and credit facilities provided by government / state banks for manufacturers

In Q3 2010, the following loan and credit facilities were issued by Chinese banks to Chinese manufacturers (data from "Mercom Capital Group"):

- $8.9B credit facility by China Development Bank given to LDK Solar,
- $5.3B loan by China Development Bank Corp. to Yingli Green Energy,

- $4.4B loan by China Development Bank to JA Solar,
- $1.9B credit facilities to Solarfun.

In November 2008, Suntech entered into a three-year interest free loan facility agreement in the aggregate principal amount of U.S. Dollar 2.9 million (RMB 20 million) with Jiangsu International Trust & Investment Corporation ("JITIC"), all of which has been drawn in 2008. The interest free loan from JITIC is restricted from investing in fixed assets related to the Pluto Technology [Suntech 2009, pp.150]. In February 2009, Suntech entered into a two-year long term loan facility agreement in the aggregate principal amount of U.S. Dollar 11.7 million (RMB 80 million) with China Construction Bank. The borrowing does not require any collateral or guarantee. All the facility was drawn down and bear a interest rate of 4.50% as of December 31, 2009 [Suntech 2009, pp.150].

5.3 R&D support in China

A detailed overview of R&D support measures in China is given in (Huo, Zhang, Wang, 2010).

6 Comparison of PV policy in Germany and China

The following table gives an overview of current PV policy instruments in Germany and China, categorized into: deployment support, investment support for manufacturing plants, and R&D support measures.

	Germany	**China**
Deployment support	• €4,270 million (¥41,025 million) Present value of PV feed-in tariff subsidy in Germany (ø p.a., 2003-2009) • KfW loans for PV investments	• Golden Sun: €482 million (¥4,821 million) (2009) • Feed-in tariff by Jiangsu Province: €302 million (¥3,017 million) (2009) • Loan guarantee for utilities by government held parent group
Investment support for manufacturing plants	• €650 million (¥6,245 million) (2008) - Joint Task (Federal / State Level) - European Regional Development Fund - Investment Allowance (in Eastern Germany) - Reduced-Interest Loans (KfW and	• Innovation fund for small technology-based firms: €2 million (2009) (¥20 million) • Refund or exemption of land fee and tax by local government (€X million) • Loan guarantee by government or government held group.

	State Development Bank Loans) - Public Guarantees (State / Federal)	• Loan and credit facilities provided by government / state banks
R&D support	• BMU: €40 million (¥384 million) (2008) • BMBF: €20 million (¥192 million) (2008) • EU support (e.g. FP7)	• 863, 973, key tech program: €4.36 million (2009) • High tech industry development by NDRC: €5 million (¥50 million) • Refund of import and value added tax for R&D equipment (€X million)

Table 6.1: PV support measures in Germany and China

(Exchange rate as of 1.7.2009 (¥1 = €0.10377))

Deployment support

Photovoltaic technologies are not yet cost-competitive as power generation and greenhouse gas mitigation options. Cost reductions are anticipated through innovation, economies of scale and learning by doing (LbD) by PV manufacturers and equipment suppliers. Private sector investors often do not have the incentive to finance this innovation, as returns from this type of investment are diffused by knowledge spillovers, inappropriable LbD, and the sharing of future rents among a large number of actors which contribute to the final products. Publicly-supported deployment programs have become extensively used and have succeeded in attracting expertise and delivering cost reductions.

The main mechanism to deliver deployment support in Germany has been the feed-in tariff (Renewable Energy Sources Act, EEG). This policy has been successful in that it has led to numerous projects being developed and financed. However, the German experience highlights aspects that need improvement. In 2009, PV module prices declined unexpectedly quickly. The resulting increase in profitability led to larger than anticipated deployment volumes, and the higher volumes led to an increase of public subsidies provided to newly-installed models (through a lifetime guaranteed feed-in tariff) from a seven-year average of €4 billion, to €10 billion in 2009 and similar levels for 2010. This points to the need for more decisive adjustments of feed-in tariffs in response to changing model prices in such a highly dynamic environment, using automated procedures or quick and transparent political processes.

In China, a combination of large-scale demonstration projects, feed-in tariffs has been applied, and the scale of support has been increased to €800 million for 2009. These deployment schemes resulted in a strong increase of annual installation in 2009.

Investors seek guidance on the future levels of targeted support in order to plan and justify investments. Continued support in Germany and increasing support for deployment in China and other regions of the world could provide this support and encourage investment. Expectations about continued growth in volumes encourage investors to explore innovation opportunities and thus support future improvements.

Investment support for manufacturing plants

PV manufacturers benefit directly (and equipment suppliers indirectly) from investment support measures for PV manufacturing plants in both China and Germany, including direct subsidies, reduced taxes, public guarantees, and interest-reduced loans. An important policy question is the extent to which linking support policies to innovation requirements improves or accelerates technology development and, if so, the extent to which such linkages would benefit from coordination on a national and international level. Currently, regional policies for supporting investments in manufacturing plants are not linked to R&D criteria in China. In Germany, innovation requirements within German investment support policies are either relatively weak or do not exist at all. The EU Commission has to approve the provision of public support according to the EU State aid rules, and would be in a suitable position to enforce stringent innovation requirements – which local agencies might not enforce where investors threaten to locate investments in other European regions.

R&D support

Much of the motivation for the deployment and investment support for photovoltaics is to support technology improvement. This indirect support is warranted wherever direct R&D support: cannot be targeted to the relevant actors; does not provide appropriate incentives; and cannot facilitate feedback from the interaction between producers and users. That said, there are likely to be instances where direct R&D support could be an effective and efficient tool for achieving technology development.

The value of PV R&D support schemes constitutes only about 3% of the value of deployment support in Germany and about 1% in China. Additional opportunities for direct R&D support exist:

- to use R&D to explore new options / technologies (since the private sector typically only focuses on technologies close to market stage);
- to enhance public co-funding of private innovative / R&D activities – and further refine the trigger and target points for such R&D support. One option is to link public R&D support to private R&D expenditures (co-funding) [example: Chinese R&D support program 863].

PV technology has clearly become a global industry, with innovation, equipment production, manufacturing of wafers, cells and modules, and deployment pursued across the world. Despite the global nature of industry, public support to date has been provided primarily within national R&D and deployment programs. To date, this has been a recipe for success. Attempting formally to coordinate national programs might create delays that would risk the commercial viability of equipment suppliers, cell manufacturers and project developers.

However, there are two factors which might be essential to address for the successful further pursuit of global PV strategy.

First, a disproportionate share of the global deployment effort was shouldered by German consumers in the years 2009/2010 and, to maintain overall support for the German renewables policy, the scale of support dedicated to German PV deployment will be reduced in 2011. Maintaining the momentum in technology development will likely require additional countries to fill the deployment gap left by the reduction in German support. China's increase in its support programs to the level of €800 million for the year 2009 has been a successful start.

Second, with the expansion and higher profile of the PV industry, it has also moved on to the radar of competing industries, as illustrated by a recent submission by the US steel workers' union to the US President requesting assessment of WTO compatibility of PV support programs. This development creates the opportunity to strengthen the linkage of public support to R&D and innovation requirements, so as both to address potential WTO concerns and to enhance the incentives for innovation. Transparency about support programs, and technology achievements and needs will be an important aspect of addressing concerns and allowing government agencies to ensure that public support programs deliver the desired innovation.

If the PV industry and associated research institutions succeed in delivering the final cost reduction by 50%, then all countries can benefit from the available technology for energy supply and the resulting global emission reductions. This creates strong incentives for informal international coordination of PV policies, so as to balance the contribution to deployment support programs. Deployment support on a global scale allows technology and industry expertise to advance further and reduces the inherent volatility of any national deployment program.

Information access facilitates the effective assessment of, and decisions by, private and public actors. Transparent information about the performance of technologies, public policies, and deployment volumes:

- allows private actors to identify technology improvement needs and opportunities;
- allows private innovators and financers to target their actions and commitments;

- supports the ongoing improvement of design and implementation of technology support programs;
- increases the level of public accountability to balance the vested interests of stakeholders and facilitates transparent assessments of supported projects and technologies.

However, private companies have incentives to retain private information to gain competitive advantage and to improve their negotiation position in public policy design choices. Policy makers and administrations are also frequently reluctant to enforce stringent transparency requirements where they would forgo informational advantages or when public information could make them more accountable to third parties. This is a fundamental challenge: every actor prefers to guard information, but all actors and society would benefit from more access to information.

7 Conclusion

We assess what contribution PV could make to energy supply in three potential scenarios – with future deployment dominated by crystalline wafer-based PV, thin film technologies, or multi-junction devices. With a constrained deployment area, more efficient technologies can make larger contributions to energy supply. This may be a significant effect that will have to be considered by policy makers in supporting specific PV technologies. A key finding in our review of PV potential is that building integrated PV could provide 31% of power in Germany and 29% of power in China. With free space installations, these numbers increase to 71% in Germany and around 100% in China.

The net benefits of public incentive schemes depend upon the extent to which the performance and costs of technologies improve over time. Although PV electricity generation is still the most expensive form of renewable power production today, the costs of PV cells have fallen rapidly over recent decades. Consequently, we evaluate the categories of potential future technology and cost improvements along the PV production chain. We find that, because various components play important roles in total pricing, it does not suffice to improve costs in just one production component, but that costs must be reduced throughout the value chain.

Technology improvements and cost reductions result from individual actors exploring improvement opportunities and alternatives. Focusing on China and Germany, we review the industry structure in which the different actors in the PV production process and equipment suppliers operate, so as to assess incentives and opportunities for these actors to pursue innovative activities. Furthermore, we analyze the level of concentration and integration across segments of the PV value chain and between PV manufacturers and equipment suppliers.

Finally, we review the design and implementation of existing technology policy support for PV in China and Germany, in order to understand whether the policy framework accounts for observed innovative performance. To the extent that there are discrepancies between the potential for technology improvements along the PV value chain and the level of innovative activity of the different actors, we review possible technology policy, competition policy and regulatory instruments that might improve the situation. In our review, we find that deployment support schemes have become extensively used and succeeded in enabling PV projects and delivering cost reductions. However, we find that investment support is not sufficiently linked to R&D criteria in either Germany or China, and that R&D support in both countries is very small relative to deployment support.

The public policy debate with regard to photovoltaics is increasingly focusing on national industrial policy objectives. In Germany, actors are increasingly concerned that the large PV feed-in tariff program is benefiting Chinese PV manufacturers at the expense of the development of German industry and at high costs for German electricity consumers. In China, actors are concerned that many technologies and much of its manufacturing equipment are imported without creating strong independent innovation capacity, thus possibly resulting in much of the profit margin remaining with foreign equipment manufacturers. At the province / city level in China and state level in Germany, the main interest is in developing a manufacturing industry which will enhance local employment and GDP.

These local perspectives – and the resulting policy responses – could limit PV innovation and endanger continued public support. It is thus important to focus on the common target of future cost reductions. Both Germany and China are interested in low-cost and sustainable power supply as well as increased security of energy supply, and therefore in the success of large-scale PV electricity supply. PV cost reductions – i.e. cheap, green electricity – will benefit all countries. Both countries know that there are costs for early investment, but also opportunities for successful early movers in the global market. PV deployment will depend on the following:

- PV technology will be applied on a large scale in China if produced locally with cheaper production costs. Localization of technology is essential, and needs to be continued.
- PV deployment support in Germany can only be maintained if this benefits both global technology improvement and German industry.
- PV deployment support in China depends upon the value attributed to technology for Chinese exports and domestic use.

PV technology will work on a large scale if costs are halved. This requires further innovation by various parties and across many countries. Thus, a key question for national and international policymakers is: how can a common global vision of PV as an essential future environmental technology guide the design and implementation of national PV technology policies?

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