Evaluation of photovoltaic technology policy

How does the technology policy mix perform to capture the technical potential of photovoltaics? A comparison of the current situation in Germany and China

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Abstract
Technology policy operates on in a world of uncertain innovation – optimal policy design therefore has to be tested against different potential scenarios of technology development. We first assess what contribution PV could make to energy supply in three potential scenarios – with future deployment dominated by crystalline PV, thin film, or multi-junction devices. Subsequently we evaluate for each scenario the categories of potential technology and cost improvements and identify actors that can contribute to these improvements. With focus on China and Germany, we review the industry structure, as well as the design and implementation of existing technology policy support for PV. To the extent that discrepancies between the potential for technology improvements and observed innovative activity of the different actors are observed, we will review possible technology policy, competition policy and regulatory instruments that might improve the situation.

Keywords Photovoltaics, Technology Policy, Innovation, Investment in R&D

1 Introduction
Technology policy design has to be tested against different potential scenarios of technology development, as the net benefits of public incentive schemes depend on the extent to which the performance and costs of technologies improve over time. Photovoltaic (PV) electricity generation is still the most expensive form of renewable power production today, although the costs of PV cells have fallen by a factor of 100 since the 1950s ([Nemet(2006)]) ##update?##. Based on literature review we have identified three potential scenarios – with future deployment dominated by crystalline wafer based PV, thin film technologies, or multi-junction devices.
Based on the current understanding of available space in building environments and free space areas, we first assess the potential contribution of PV to electricity supply in the different scenarios. With constrained deployment area, more efficient technologies can make larger contributions to energy supply. Is this a significant effect that will have to be considered by policymakers in supporting specific PV technologies? Subsequently we evaluate the categories of potential technology improvements and cost reductions along the PV production chain and differentiated according to an improvement of the PV cell, the production process of the cell, or the equipment used for the production of the solar cell.

Technology improvements and cost reductions result from exploration of improvement opportunities and search for alternatives by individual actors. With focus on China and Germany, we describe the industry structure that hosts the different actors in the PV production process and among equipment suppliers, so as to assess incentives and opportunities for these actors to pursue innovative activities. After analysing the level of concentration and integration across segments of the PV value chain and between PV manufacturers and equipment suppliers, we use different indicators to describe the level of innovative activity of the different actors in China and Germany.

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 explains observed innovative performance. To the extent that discrepancies between the potential for technology improvements along the PV value chain and the level of innovative activity are observed, we will review possible technology policy, competition policy and regulatory instruments that might improve the situation.

2 Photovoltaics: Technical potential and cost reduction potentials

2.1 Photovoltaic technologies

The global PV market is dominated by single-junction solar cells based on mono- and multicrystalline silicon wafers. These devices currently account for 90% of PV production ([#1]). Thin-film technologies (single-junction) are characterized by reduced costs of active material and by slightly lower efficiencies.
An overview of the different photovoltaic technologies with their respective cell technology shares, cell efficiencies and module efficiencies is given in Table 2.1.

### Photovoltaic technologies

<table>
<thead>
<tr>
<th>Technology</th>
<th>Crystalline wafer based (single-junction solar cells based on silicon wafers)</th>
<th>Thin Film (single-junction)</th>
<th>Multi-junction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mono-crystalline /single crystal (c-Si)</td>
<td>Amorphous silicon (a-Si)</td>
<td>CdTe</td>
</tr>
<tr>
<td>Cell technology shares (in 2007)</td>
<td>42.2%</td>
<td>5.2%</td>
<td>4.7%</td>
</tr>
<tr>
<td>Cell Efficiency at STC* [%]</td>
<td>16-19%</td>
<td>5.7%</td>
<td>8-11%</td>
</tr>
<tr>
<td>Module Efficiency [%]</td>
<td>13-15%</td>
<td>12-14%</td>
<td></td>
</tr>
<tr>
<td>Module Efficiency** [%]</td>
<td>22.9 ± 0.6</td>
<td>15.5 ± 0.4</td>
<td>10.4 ± 0.5</td>
</tr>
</tbody>
</table>

* Standard Testing Conditions: 25°C, light intensity of 1,000 W/m², air mass = 1.5
** Confirmed terrestrial module efficiencies measured under the global AM1.5 spectrum (1000 W/m²) at a cell temperature of 25°C

[*] Sources:

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

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 which exhibit high costs for purification. Advantages of thin-film PV are lower costs per watt at module level, mainly due to the minimal requirement of silicon, production processes in one casting, and a higher temperature coefficient, i.e. the module’s efficiency is not affected by high temperatures. However, the drawbacks of these technologies are greater surface area requirements due to lower
efficiency and higher generation costs because their standard degree of efficiency is generally lower. Moreover, some input materials (as Te) are rare elements, and other materials (as Cd) are even a hazard for human health.

If different concepts were used in the design of solar cells, their performance could be further improved, to produce a new generation of high performance, low-cost photovoltaic technology ([Green(2003)]). Possible ideas discussed over the last twenty years include 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-sensitised cells ([Grätzel(2001)]). However, most of these concepts have proven very difficult to demonstrate in principle.

The only proven new technology is that based on the use of multiple junctions ([Green(2006)], [Yoshimi et al.(2003)]). In order to utilize the entire solar spectrum, multi-junction devices stack different solar cells with multiple bandgaps. For two- (tandem), three- and four-junction devices, maximum efficiencies of 55.9%, 63.8% and 68.8% are predicted ([Green(2006)]). In our third scenario we assume that multiple junction devices achieve the anticipated performance characteristics and can capture a large market share.

Figure 2.1: Schematic cross-section of the Spectrolab triple-junction cell ([Karam et al.(1999)])
2.2 Technical potential of photovoltaics within different scenarios

Optimal PV policy design has to be tested against different potential scenarios of technology development, as technology policy operates on in a world of uncertain innovation. Based on literature review we have identified three potential scenarios, which are given in Table 2.2. In this section, we assess what contribution PV could make to energy supply in these scenarios. Within the first scenario we assume that technology shares stay constant until 2020. Thin film and multi-junction devices will become the dominant PV technologies in the second and third scenario respectively.

The purpose of this exercise is twofold. First, we want to assess, whether some technology trajectories are preferable and should thus obtain preferred support. Second, given the uncertainty about future cost and efficiency performance and potential resource and environmental constraints, we want to ensure that a policy technology mix supports a portfolio of technology developments so as to learn about their relative cost and performance.

<table>
<thead>
<tr>
<th>PV scenarios</th>
<th>Crystalline mainly</th>
<th>Thin Film mainly</th>
<th>Multi-junction mainly</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technology share in 2020 [%]</td>
<td>crystalline</td>
<td>thin film</td>
<td>multi-junction</td>
</tr>
<tr>
<td>crystalline</td>
<td>90%</td>
<td>10%</td>
<td>20%</td>
</tr>
<tr>
<td>thin film</td>
<td>10%</td>
<td>90%</td>
<td>20%</td>
</tr>
<tr>
<td>multi-junction</td>
<td>0%</td>
<td>0%</td>
<td>60%</td>
</tr>
</tbody>
</table>

Table 2.2: Potential scenarios of technology development

To assess the potential contribution photovoltaics could make to our power generation, we review the available space in building environments and free space areas (Tables 2.3 and 2.4). The estimations of available areas in Germany vary between 1000 km² and 5178 km², due to different assumptions about suitable roof-top area, free space areas that can be covered with PV, and the share of different areas that are reserved for solar thermal applications. In the following sections, we will base our calculations on the numbers given by Quaschning (2000). The Chinese study assumes that 20% of roof-top and façade and 1% of the Chinese desert surface can be covered with PV ([###?]).
Table 2.3: PV area potential in Germany [km²]

<table>
<thead>
<tr>
<th>Roof-top</th>
<th>Façade</th>
<th>Residential / traffic areas</th>
<th>Free space</th>
<th>Sum</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>800</td>
<td>/</td>
<td>/</td>
<td>3518</td>
<td>4318</td>
<td>Kaltschmitt (1993)</td>
</tr>
<tr>
<td>200 (1)</td>
<td>150</td>
<td>350 (2)</td>
<td>300 (3)</td>
<td>1000</td>
<td>Nitsch (1999)</td>
</tr>
</tbody>
</table>

(1) 25% of 800 km²; 600 km² for solar thermal applications
(2) 50% of 700 km²; 350 km² for solar thermal
(3) 45% of 650 km²; 350 km² for solar thermal
(4) 66% of 1304 km²; 440 km² for solar thermal

Table 2.4: PV area potential in China [km²]

<table>
<thead>
<tr>
<th>Roof-top</th>
<th>Façade</th>
<th>Free space</th>
<th>Sum</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>4000</td>
<td>1000</td>
<td>12000</td>
<td>17000</td>
<td>NDRC, China PV industry development report 2004; NDRC, China PV development report 2007</td>
</tr>
</tbody>
</table>

Figure 2.2 shows a comparison of the future technical potential of photovoltaics in China and Germany.
With constrained deployment area, more efficient technologies can make larger contributions to energy supply. Using these assumptions on space availability, building integrated crystalline PV could provide .% of power in Germany and .% of power in China, with free space installations these numbers increase to xx% in Germany and xx% in China.

While these numbers are ##% smaller within the thin film scenario, more than 100% of Chinese (and almost 2/3 of German) electricity consumption could be served by photovoltaics in the case of a possible breakthrough of a new multi-junction technology. System requirements, in particular electricity storage, are not considered in this assessment.

### 2.3 Cost development of PV

Photovoltaic costs have demonstrated a fascinating development over the last four decades. Figure xxx illustrates how their costs have fallen by a factor of 100 since the 1950s [Nemet 2006]. In this broad perspective, the necessary cost reduction in the order of a factor 2-4 for competitiveness at large scale is worthwhile to consider. Figure 2.3 looks into more detail of the development in China and Germany over the last years. Despite a large increase in deployment volumes in the period 2003-2008, the prices stayed relatively stable in that period. In general this is attributed to scarcity in production capacity, in particular for purification of silicon but increasingly also wafer production. Unexpected demand growth, driven by rapidly changing renewable support schemes across the globe, resulted in demand increases that exceeded production capacity, and thus created scarcity rents. By 2009 the production capacity finally exceeded short-term demand reducing the rent captured.
Figure 2.3: National trend in PV system and module prices in China and Germany

Figure 2.4 illustrates an additional dimension of the recent development. Much of the new production capacity was built in China – a development explored in more detail in section xx. Thus Chinese producers were aiming to increase their market share in other parts of the world. These producers increased their exports, e.g. to Germany. Based on data from an online platform for sales of PV modules, Chinese producers offered models persistently at lower prices than their German competitors. The international competition did then succeed in creating a downward pressure on prices for German modules.
Figure 2.4: Average net price of crystalline modules from Germany and China
[Source: Data from pvXchange GmbH (2008-2010)]

2.4 Photovoltaic value chain, illustrated with cost components

The major components of the solar PV value chain are shown in Figure 2.5, for both crystalline-based approaches and thin film technologies.

Figure 2.5: PV value chain (crystalline and thin film)
[Source: Deutsche Bank, Solar Photovoltaic Industry, January 2009]

The first four production stages of crystalline wafer based devices are referred to as (crystalline) production chain:

1. Silicon feedstock production and ingot manufacturing
2. Wafer production
3. Solar cell production
4. Module production
Price and cost structure in China in 2009:
We compare cost structure and price structure of four stages along the supply chain in China. Processing cost equals that total production cost minus material cost. It reflects that cost of labor, energy, fixed input, management and others. Material cost equals that material price multiple its consumption per watt.

- Polysilicon processing cost is much higher than that of other stages, about 97% of polysilicon cost. Wafer and module processing production is similar, while separately they account for 33% of wafer cost and 13% of module cost. Cell processing cost is lower comparatively, only about 8.7% of cell cost.
- Material cost of polysilicon production is much lower than that of other stages, about 3.3% of polysilicon cost. Material cost of cell production is as high as 91%, and that of wafer and of module separately is 68% and 87%. So the processing cost of polysilicon has biggest impact on final module cost.
- Sales margin of polysilicon is biggest as 33%. That of module is lowest as 11.8%.
2.5 Technology improvement potential (including cost reduction)

In this section, we review for each scenario the categories of potential technology improvement – differentiated according to the stages of the PV production chain and differentiated according to an improvement of the PV cell, the production process of the cell, or the equipment used for the production of the solar cell. This analysis is intended to increase our understanding of:

- Technology improvement / cost reduction potentials in the different scenarios
  - Technology improvements
  - Improvement of the production process
  - Scale effects
  - Localisation of technology / production to countries with lower labor costs
- Assessing to what extent experience gathered with the development and deployment of one PV technology can be translated to other PV technologies should they demonstrate better performance

<table>
<thead>
<tr>
<th>Supply chain</th>
<th>Factor</th>
<th>Drivers of change (hypothesis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ingot</td>
<td>Ingot casting</td>
<td>Spillover (in the past)</td>
</tr>
<tr>
<td>Wafer</td>
<td>Kerf loss</td>
<td>Spillover</td>
</tr>
<tr>
<td></td>
<td>Wafer thickness</td>
<td>Spillover (in the past)</td>
</tr>
<tr>
<td></td>
<td>Wafer size</td>
<td>Learning by doing</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>Learning by doing</td>
</tr>
<tr>
<td>Cell</td>
<td>Cell efficiency</td>
<td>R&amp;D</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>R&amp;D, LBD</td>
</tr>
<tr>
<td></td>
<td>Lifetime</td>
<td>R&amp;D, LBD</td>
</tr>
<tr>
<td></td>
<td>Yield</td>
<td>Learning by doing</td>
</tr>
<tr>
<td>Total</td>
<td>Cycle time</td>
<td>Learning by doing</td>
</tr>
</tbody>
</table>

Table 2.5: Technology improvement opportunities for crystalline PV
Table 2.6: Technology improvement opportunities for thin-film PV

<table>
<thead>
<tr>
<th>Supply chain</th>
<th>Factor</th>
<th>Drivers of change (hypothesis)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Module</td>
<td>Module efficiency</td>
<td>R&amp;D</td>
</tr>
<tr>
<td></td>
<td>Module size</td>
<td>Learning by doing</td>
</tr>
<tr>
<td></td>
<td>Stability</td>
<td>R&amp;D, LBD</td>
</tr>
<tr>
<td></td>
<td>Lifetime</td>
<td>R&amp;D, LBD</td>
</tr>
<tr>
<td>Total</td>
<td>Production yield</td>
<td>Learning by doing</td>
</tr>
<tr>
<td></td>
<td>Cycle time</td>
<td>Learning by doing</td>
</tr>
</tbody>
</table>

Conclusion
PV costs have fallen drastically over the last fifty years. Can this downward trend be maintained for a few more years, so as to make PV cost competitive with existing power generation technologies? The analysis of the last years demonstrates that the trend towards cost reductions has continued – with typical temporary deviations due to price-cost margins. Further cost reductions will be necessary across a set of components of the value chain. The technical options of potential cost improvements across these sets of value chains exist. The next section explores who are the actors that might pursue these improvements.

3 Description of the industry
Technology improvements and cost reductions result from exploration of improvement opportunities and search for alternatives by individual actors. We need to understand the industry structure that hosts the different actors in the PV production process and among equipment suppliers, so as to assess incentives and opportunities for the actors to pursue innovative activities.

3.1 Actors contributing to cost reductions / technology improvements
Identifying actors that can contribute to cost reductions / technology improvements

- Different stages of PV production chain
- Suppliers of equipment to different stages
- Installation and maintenance
In the following section, we describe the current PV industry structure in China and Germany, including the level of concentration and integration across segments of the PV value chain and between equipment suppliers and manufacturers.

### 3.2 Industry structure in Germany

Germany was the world’s largest PV market in 2008, with 37% of total globally installed PV power. German PV industry turnover surpassed the EUR 9.5 billion mark in 2008, while PV equipment supplier turnover accounted for additional EUR 2.4 billion [GTAI 2009]. While the export share of manufacturers increased from 14% in 2004 to 48% in 2008, the export share of suppliers is even higher (see Figure 3.1).

![Figure 3.1: Export share of PV companies in Germany (in percent)]

[Source: BSW 2009]

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 57000 people. Photovoltaic cell and module production in Germany amounted to 1383 MWp and 1243 MWp respectively in 2008 [GTAI 2009]. Figure 3.2 shows the biggest PV manufacturers in Germany with their respective capacities in 2009 along the (crystalline) PV production chain.
The number of companies at the first stage of the PV production chain is relatively small, as silicon production and processing requires intensive technical knowledge and substantial investment. In Germany, this stage is dominated by Wacker Chemie AG, one of the world’s leading silicon suppliers for the PV and semiconductor industries.

Towards the end of the production chain, the number of manufacturers is larger due to lower investment requirements and less intensive knowledge. There are also fully integrated companies (having operations in the wafer, cell, and module parts of the value chain) like SolarWorld, Conergy, or Sovello.

Figure 3.3 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 like for instance tabbers and stringers for crystalline modules.
Figure 3.3: PV equipment manufacturers in Germany
(Note: In the legend only companies are shown with more than 400 empl.)

Figure 3.4: PV equipment manufacturers in Germany – sector background
Highly developed supporting industries, especially in semiconductors, chemicals, optics and glass have been instrumental for the successful development of the German photovoltaic cluster. Figure 3.4 shows the activities of the equipment manufacturers in the related semiconductor, medical, and automotive industries.

### 3.3 Industry structure in China

![Figure 3.5: PV manufacturers in China along production chain](image)

[Source: Company websites; CRESP, China PV industry development report 2008]

In each sector, we surveyed seven companies with biggest capacities, or companies whose capacities in total account for more than 75% of the whole sector in 2009. The figure indicates six silicon manufacturers, other silicon manufactures, six wafer manufacturers, other wafer manufacturers, seven cell manufacturers, other cell manufacturers, seven module manufacturers, other module manufacturers. The company currently integrating production in several sectors is Yingli, including wafer, cell and module.

Polysilicon production is seldom to be integrated with any other stages. Supply does not meet demand with high profit and it threatens development of downstream production. So last five years
it attracts increasing attention of investment, especially from downstream to integrate. But it is not easy to access and manage. Investment cost is big because of long production line. And process technology is complex and unavailable to transfer, while Chinese institutes developed new Siemens technology many years after transferring undeveloped technology from Russian Institute. And it requires active technology innovation to catch up fast technology development. Tianwei Baobian have 35.66% of stock of Xinguang polysilicon producer and 25.99% of Yingli cell producer.

Wafer production is also seldom to be integrated with any other stages. While supply meets demand well in such a good competition market, profit is not high and it does not threat downstream development as polysilicon. Still integration helps cell producer reduce cost, but it is not easy to access because it is capital intensive though process technology and equipments are easy to import. Only Yingli cell producer integrates wafer production, while it has big capital capacity and pursue strategic cost reduction.

Module is the most popular to be integrated with other stages. A lot of big cell producers own module production line. Module integration helps cell producers enlarge profit and it is easy to access. Process technology and equipment are easy to buy, and high labor intensity is cheap to reach. After global financial crisis, module supply exceeds demand especially while European PV market decreases. Small unintegrated module producers are difficult to survive when price decreases.
Figure 3.6: PV equipment manufacturers in China

[Source: websites of companies]

We surveyed equipment suppliers for each sector, whose employee for specific sector is comparatively larger. The figure indicates three silicon equipment suppliers, twelve ingot or wafer equipment suppliers, ten cell equipment suppliers, nine module equipment suppliers, three thin-film equipment suppliers. Most integration happens between equipment supply of ingot or wafer and that of cell, while there are five companies in the figure. Besides, as the figure shows, Wanhe supplies equipment for cell and module, and Wuhan DR laser supply for cell and a-Si.

Figure 3.7: PV equipment manufacturers in China – sector background
Height of item is equal that scale of equipment manufacturers multiple percentages of industries manufactures make equipments for. Chinese polysilicon equipment manufacturers originally produce boiler and other containers for petrochemical and medical industry. They research and develop hydrogen furnace and deoxidation furnace for polysilicon industry in recent years.

3.4 Innovative activity
In this section, we use different indicators to describe the level of innovative activity of the different actors in China and Germany. Discrepancies between the potential for cost reductions in different stages of the production process / equipment provision and the level of innovative activity observed in this segment point to opportunities for an improvement of the technology policy framework.

4 PV technology policy options
What technology policy options are used to support these actors in pursuing improvements? We first review the design and implementation of existing technology policy support for PV – with focus on China and Germany and broader coverage of developments in other countries. We aim to understand whether the policy framework explains observed innovative performance.

To the extent that discrepancies between the potential of technology improvements and observed innovative activity are observed, we will review possible technology policy, competition policy and regulatory instruments that might improve the situation.
4.1 Technology policy options in Germany

Since 1991, systematic governmental support schemes for PV installations have been implemented in Germany. An initial legal basis for the remuneration of electricity generation from renewable energy sources was established by the Electricity Feed-in Act (Stromeinspeisegesetz) between 1991 and 1999. The 1,000 Solar Roofs Initiative, which was applied between 1991 and 1995, was the first PV-specific support scheme. Between 1999 and 2003 it was followed by the 100,000 Solar Roofs Initiative, which similarly provided loans at low interest rates for the funding of PV installations. These loans were granted by the state owned German development bank (KfW). A feed-in tariff scheme has been established in 2000 (Renewable Energy Sources Act, EEG), which has undergone amendments in 2004 (EEG 2004) and 2009 (EEG 2009).

Table 4.1 gives an overview of the current PV support measures applied in Germany. Within the German strategy to foster the deployment of renewable energy sources (and especially photovoltaics), the feed-in tariff scheme is the core element, being flanked by additional measures
like public support of research and development (R&D) for PV technologies and funding schemes. Therefore, we focus our analysis in the following sections on support schemes for deployment and for PV R&D.

<table>
<thead>
<tr>
<th>Enhanced feed-in tariffs</th>
<th>Renewable Energy Sources Act (EEG)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital subsidies for equipment or total cost</td>
<td>Yes, in some states</td>
</tr>
<tr>
<td>Green electricity schemes</td>
<td>Yes, some utilities offer „green electricity“</td>
</tr>
<tr>
<td>PV-specific green electricity schemes</td>
<td>no</td>
</tr>
<tr>
<td>Investment funds for PV</td>
<td>On commercial basis by banks or investment funds dedicated to renewable energies, particularly large solar power plants</td>
</tr>
<tr>
<td>Income tax credits</td>
<td>None specific for PV, but the regular depreciations by commercial investments</td>
</tr>
<tr>
<td>Net metering</td>
<td>yes</td>
</tr>
<tr>
<td>Net billing</td>
<td>yes</td>
</tr>
<tr>
<td>Commercial bank activities e.g. green mortgages promoting PV</td>
<td>yes</td>
</tr>
<tr>
<td>Electricity utility activities</td>
<td>yes</td>
</tr>
<tr>
<td>Sustainable building requirements</td>
<td>Yes, by law for new buildings, there are provisions for energy efficiency</td>
</tr>
</tbody>
</table>

Table 4.1: PV support measures in Germany

4.1.1 Support for deployment
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 kWp, 100 kWp and 1000 kWp ###) and installation types (roof-top and field installations). Table 4.2 gives an overview of the recent German PV feed-in tariffs.

<table>
<thead>
<tr>
<th>System size</th>
<th>Rooftop installations (EUR/kWh)</th>
<th>Field installations (EUR/kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>≤ 30 kW</td>
<td>30 – 100 kW</td>
</tr>
<tr>
<td>Year of installation</td>
<td>2009</td>
<td>0.4301</td>
</tr>
<tr>
<td></td>
<td>2010</td>
<td>0.3914</td>
</tr>
</tbody>
</table>

Table 4.2: PV feed-in tariffs according to German EEG

The feed-in tariffs are paid for a time period of 20 years. At the beginning of 2010, the tariffs equal a reduction of 11% and 9% (for rooftop installations ≤ 100 kW) respectively in comparison to 2009. The degression rates are set at 9% p.a. from 2011 onwards, with an adjustment of +/- 1% each year until 2012 if the amount of newly installed PV systems exceeds/falls below a certain limit in the previous year (with “growth corridors” of 1100 - 1700 MW and 1200 - 1900 MW for the years 2010 and 2011 respectively).

Figure 4.2 shows the present value of this subsidy in Northern, Central and Southern Germany. As system prices have fallen much faster in 2009 than originally expected, the German government has decided this year to cut back the feed-in tariff in July 2010 by additional 16% for roof-top installations and by ###% for ### (###).
Figure 4.2: PV feed-in tariff of the German EEG – Present value of subsidy in Southern / Central / Northern Germany
(Notes: time period of 20 years, 7% discount, 1100 / 900 / 700 PV full load hours per year in Southern / Central / Northern Germany)

Figure 4.3: Total system expenditure for PV installations in Germany
(Sources: National Survey Report of PV Power Applications in Germany 2008, Version 2 (IEA, Co-operative programme on PV power systems), Lothar Wissing, Forschungszentrum Jülich, May 2009; Statistische Zahlen der deutschen Solarstrombranche (Photovoltaïk), Bundesverband Solarwirtschaft, Nov 2009)
Table 4.3 gives an overview of applied funding schemes for market stimulation in Germany.

<table>
<thead>
<tr>
<th>Funding organisation</th>
<th>Kind of Funding</th>
<th>Name of Programme</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>By Government</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Local utilities</td>
<td>Feed-in tariff</td>
<td>EEG</td>
</tr>
<tr>
<td>Local fiscal authorities</td>
<td>Tax credits for PV investments by producing enterprises</td>
<td>Investitionszulage</td>
</tr>
<tr>
<td><strong>By Bank</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>KfW</td>
<td>Loans for private PV investments</td>
<td>Erneuerbare Energien Standard</td>
</tr>
<tr>
<td>KfW</td>
<td>Loans for PV investments by communities and their enterprises</td>
<td>Kommunal investieren</td>
</tr>
<tr>
<td>KfW</td>
<td>Loans for investment in the infrastructure of communities to save energy and change to renewable energies</td>
<td>KfW-Kommunalkredit</td>
</tr>
<tr>
<td><strong>By Federal States</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bavaria</td>
<td>Grants for PV demonstration projects</td>
<td>Rationellere Energiegewinnung – und Verwendung im Gewerbe</td>
</tr>
<tr>
<td>Hamburg</td>
<td>Grants for thin film PV installations on oof tops</td>
<td>Hamburger Klimaschutzprogramm Photovoltaik</td>
</tr>
<tr>
<td>Niedersachsen</td>
<td>Mainly loans for small and medium enterprises</td>
<td>Niedersächsisches Innovationsförderprogramm (Gewerbe)</td>
</tr>
<tr>
<td>NRW</td>
<td>Grants for buildings with high energy efficiency</td>
<td>Progress.nrw “Rationelle Energieverwendung, Regenerative Energien und Energiesparen</td>
</tr>
<tr>
<td>Rheinland-Pfalz</td>
<td>Grants for new buildings with high energy efficiency</td>
<td>Förderprogramm hochenergieeffiziente Neubauten</td>
</tr>
<tr>
<td>Saarland</td>
<td>Grants for PV installations on schools and demonstration projects</td>
<td>Zukunftsenergieprogramm Technik</td>
</tr>
</tbody>
</table>

Table 4.3: National programmes for market stimulation in Germany
[BSW Solar, Förderung von Solaranlagen in Deutschland, May 2009]

4.1.2 Public PV R&D support

The responsibility for renewable energies within the German Federal Government is taken by 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 the BMBF support for PV R&D projects amounted to 19,5 Mio. EUR in 2008 (8 cooperative R&D projects were granted), the R&D
budget for PV of the BMU accounted for 39.9 Mio. EUR shared by 130 projects [Innovation through Research, BMU, Jan 2009]. In comparison to these public PV R&D budgets, industrial R&D investments amounted to 163 Mio. EUR in 2008 [BSW Solar, Statist. Zahlen der deutschen Solarstrombranche (Photovoltaik), Nov 2009].

Figure 4.4 shows the distribution of the BMU R&D budget. While wafer based silicon technologies received almost two thirds of total R&D support (59%), around one third was allocated to thin-film technologies (32%). The remaining funds were given to the development of system technology, alternative PV technologies (e.g. concentrating PV) and crosscutting issues.

In 2008, the BMBF initiated networks aiming for the development of thin-film PV cells with focus on topics like material sciences and the use of synergies with other research fields like microelectronics. Moreover, the development of organic PV cells is addressed by a joint initiative with the industry. As part of the Federal High-Tech Strategy, the BMBF also supports the development of the “Solarvalley Mitteldeutschland” cluster, which covers most of the German PV industry.
4.2 Technology policy options in China

Figure 4.5:
[Source: Sicheng Wang, Energy Research Institute National Development and Reform Commission]

This figure shows PV market in China that is annual installation multiple system prices. It highly depends on attitude of government too as other mitigation technologies.

4.2.1 Support for market deployment

4.2.1.1 Subsidies

- Example: “Gold Sun” demonstration project by MOF (Ministry of Finance People’s Republic of China) from 2009 to 2011
  - 642MW and 1TWh/a in total for installing 290MW in commercial buildings (50% funded by subsidy), 46 MW in remote rural residential buildings (70% funded by subsidy), 306 MW of big-scale on-grid PV (50% funded by subsidy).

- Example: BIPV demonstration project by MOF
  - 20 RMB/Wp in maximum for building material integrated PV, 15 RMB/Wp in maximum for rooftops and facades installed PV

4.2.1.2 feed-in-tariff

There are more than one hundred on-grid PV projects by 12/2008 in China, in which only two projects is approved to get 4 RMB/kWh feed-in-tariff. General regulation of how to make feed-in-tariff has not been made yet. Now feed-in-tariff of each PV project is made and approved separately.
4.2.2 Support for R&D

Ministry of Science and Technology of the People’s Republic of China (MOST) is in charge of research and development in China. It has budget to support R&D in companies, universities and institutes so as to assist with every “Five Year Plan” of central government. It has three kinds of programs supporting PV R&D.

- National Basic Research Program of China(973 Program) of MOST, to support basic science research for long-term development
- National High-tech R&D Program (863 Program) of MOST, to support Innovation in strategic high-tech fields
- Key Technologies R&D Program of MOST, to support R&D for current national economic construction

The procedure is similar among these kinds of programs. After it announced budget plan and targeted R&D field of the whole program, any companies, universities and institutes could propose feasible plan to apply for specific project. And then MOST asks for a lot of experts and organize selection.

- An example of PV manufacturers: Xinguang gets one of Key Technologies R&D Program from 2006 to 2010. MOST supplies 6 million RMB for research and development of one key technology in polysilicon production.
- An example of equipment suppliers: Nanjing Chunhui and Chengdu Zhongshun get one of 863 program from 2006 to 2010. MOST supplies 29 million RMB for research and development of equipments of CPV system in MW level. They are required to invest at least 29 million RMB at the same time.

- An example of research institutes: China Academy Sciences and Nankai University get one of 973 program from 2006 to 2010. MOST supplies 30 million RMB for basic research of low price and long life thin-film PV cell.

- An example of PV developers. Shanghai Solar Technology company get one of 863 program from 2006 to 2010. MOST supplies 20 million RMB for applied research of BIPV on-grid system in MW level. The company is required to invest at least 40 million RMB at the same time.

### 4.2.3 Support for industry deployment

Energy industry growth is one of responsibilities of National Development and Reform Commission (NDRC). It has budget to support industrialization of high technology so as to assist with every “Five Year Plan” of central government. It manages and supplies funds for High-tech Industry Development Program. After NDRC announced industries to give subsidy for investment or interests of loan, any companies could propose feasible plan of specific projects and then NDRC arrange selection.

An example of PV manufacturers: Trina Solar get one of High-tech Industry Development Program from 2007. NDRC supplies 3 million RMB for development of thinner and bigger mono-silicon wafer

### 4.3 Criteria

1. match of observed innovative activity and anticipated improvement potential (across actors and value chain)

2. Strategic deployment
   a. Creates revenue and incentives for earlier stages – more predictability growth – more innovation for future market
3. Support for different stages of value chain
   a. Investment support – revenue for equipment suppliers
   b. not linked to innovation (China and Germany)
4. R&D and demonstration projects

5 Conclusion

We have deliberately left the concluding section open at this stage of the research to enable further comments and feedback from the discussions arising at upcoming presentations.

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