Solar Photovoltaics Deployment Policy Design

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Abstract

Solar energy is the largest energy resource on earth, with resources being clean, sustainable and distributed around the globe. Photovoltaics (PV) technologies directly convert sunlight to electricity. Solar PV can provide multiple economic and environmental benefits to society, and has the highest learning rate in the energy world. The rapid market growth of PV in recent years has been driven by policies to support deployment and technology development. However, PV electricity in many countries is not yet competitive with conventional power generation sources, and therefore needs a financing framework with stable returns. Economic justifications to further support PV technologies include their substitution for fossil fuel technologies with environmental externalities, and the encouragement of technological learning.

This dissertation aims to contribute to the development and design of effective and efficient policies to remunerate solar PV power generation. The doctoral thesis consists of three self-contained papers, which can be read independently.

Paper I ‘Survey of Photovoltaic Industry and Policy in Germany and China’ focuses on two countries with significant PV policy achievements. While Germany has been the largest market for PV installations for many years, China has become the largest manufacturer of solar cells and modules. Based on an assessment of the technical potential of PV technologies and their required cost reductions to become a competitive electricity source, the paper analyzes the industry structure as well as PV policies used by Germany and China to support research and development, investment in manufacturing plants, and deployment.

Paper II ‘Responsive Feed-in Tariff Adjustment to Dynamic Technology Development’ develops an analytic model to simulate PV installations and feed-in tariffs based on project profitability and project duration. As PV deployment around the world has been mainly driven by feed-in tariff policies, this model allows to analyze the effectiveness of different feed-in tariff designs. The analytic framework accurately replicates observed PV market developments in Germany, and is used to analyze different feed-in tariff adjustment mechanisms against multiple PV system price scenarios.

Paper III ‘Comparison of Feed-in Tariffs and Tenders to Remunerate Solar Power Generation’ analyzes the trade-offs for using feed-in tariffs or tenders to remunerate different scales of PV projects. The paper quantifies deployment effectiveness of flexible feed-in tariff schemes across project sizes and uses semi-structured interviews with German and French project developers to explore how feed-in tariffs and tenders impact cost of capital and transaction costs.

Keywords: Solar photovoltaic; Technology policy design; Feed-in tariff; Tender; Renewable energy deployment.

Zusammenfassung

Solarenergie ist die größte Energieressource auf der Erde und zeichnet sich durch Nachhaltigkeit, Sauberkeit und globale Verfügbarkeit aus. Photovoltaik (PV) Technologien wandeln Sonnenlicht direkt in elektrische Energie um. Die Photovoltaik bietet der Menschheit zahlreiche ökonomische und ökologische Vorteile und besitzt die höchste Lernrate in der Energiewelt. Politikinstrumente zur Förderung des Ausbaus und der technologischen Entwicklung haben das schnelle Marktwachstum der PV in den letzten Jahren ermöglicht. Allerdings ist PV Strom in vielen Ländern noch nicht wettbewerbsfähig mit Strom aus konventionellen Kraftwerken und benötigt daher stabile finanzielle Rahmenbedingungen. Die weitere Förderung der Photovoltaik wird ökonomisch durch die Substitution fossiler Brennstofftechnologien mit externen Kosten und die Unterstützung technologischer Entwicklung begründet.

Diese Dissertation hat das Ziel einen Beitrag zu Entwicklung und Design effektiver und effizienter Politikinstrumente zur Vergütung solarer Stromerzeugung zu leisten. Die Dissertation besteht aus drei eigenständigen Arbeiten, die unabhängig voneinander gelesen werden können.

Artikel I 'Survey of Photovoltaic Industry and Policy in Germany and China' analysiert zwei Länder mit signifikanten PV politischen Errungenschaften. Während Deutschland für viele Jahre der größte Markt für PV Installationen war, entwickelte sich China zum größten Produzenten von Solarzellen und –modulen. Basierend auf einer Berechnung des technischen Potenzials verschiedener PV Technologien und der erforderlichen Kostenreduktionen zur Erreichung der Wettbewerbsfähigkeit untersucht der Artikel für beide Länder Industriestruktur und Politikinstrumente zur Förderung von Ausbau, Investitionen in Produktionsanlagen, sowie Forschung und Entwicklung.

Artikel II 'Responsive Feed-in Tariff Adjustment to Dynamic Technology Development' entwickelt ein analytisches Modell zur Simulation von PV Installationen und Einspeisevergütungen. Da der globale PV Ausbau hauptsächlich durch Einspeisevergütungen ermöglicht wurde, erlaubt dieses Modell die Analyse der Effektivität unterschiedlicher Vergütungssysteme. Das Modell bildet die beobachteten Marktentwicklungen in Deutschland präzise ab, und dient der Untersuchung verschiedener Anpassungsmechanismen für Einspeisevergütungen im Rahmen zahlreicher Systempreis Szenarien.

Artikel III 'Comparison of Feed-in Tariffs and Tenders to Remunerate Solar Power Generation' untersucht Einspeisevergütungen und Ausschreibungen zur Förderung unterschiedlicher PV Projektgrößen. Der Artikel quantifiziert die Effektivität flexibler Einspeisevergütungs-mechanismen für verschiedene Projektgrößen und nutzt semi-strukturierte Interviews mit deutschen und französischen Projektentwicklern um die Auswirkungen von Einspeise-vergütungen und Ausschreibungen auf Kapitalkosten und Transaktionskosten zu erforschen.

Schlüsselwörter: Solar Photovoltaik; Technologie Politik Design; Einspeisevergütung; Ausschreibung; Erneuerbare Energien Ausbau.

Acknowledgements

Writing my Ph.D. dissertation was an energy intensive process and a greatly rewarding time. I therefore want to acknowledge the support of all people who accompanied me on this way during the last years.

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Thilo Grau

Rechtliche Erklärung

Hiermit versichere ich dass ich die vorliegende Dissertation selbständig und nur unter Verwendung der angegebenen Literatur und Hilfsmittel angefertigt habe. Die Arbeit wurde noch keiner Prüfungsbehörde in gleicher oder ähnlicher Form vorgelegt.

Berlin, Mai 2014

Thilo Grau

“All religions, arts and sciences are branches of the same tree. All these aspirations are directed toward ennobling man’s life, lifting it from the sphere of mere physical existence and leading the individual towards freedom.”

Albert Einstein

Opening words to "Moral Decay," a message to Young Men's Christian Association on its Founder's Day, October 11, 1937. Quoted in *Out of My Later Years*, 16. Einstein Archives 28-403.

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1 Introduction

1.1 Research background and motivation

Renewable energies can provide multiple benefits to society, like mitigating climate change, increasing energy security, improving economic development, facilitating energy access, as well as environmental and health benefits (IPCC, 2011). There is comprehensive scientific evidence for the existence of anthropogenic climate change (IPCC, 2007), with energy emissions representing around two-thirds of global greenhouse gas (GHG) emissions (Stern, 2008). Economic justifications to support renewable energy technologies include their substitution for fossil fuel technologies with environmental externalities (carbon dioxide emissions), and the positive learning by doing externality. 127 countries have implemented policies to support the deployment and development of renewable energy technologies (REN21, 2013).

Solar energy is the largest energy resource on earth. The sunlight striking this planet in 85 minutes could provide the entire energy consumed by humankind for one year (IEA, 2011). The global yearly solar energy potential exceeds annual world energy consumption by a factor of 1400, is more than 200 times larger than all other renewable resources combined, and 14 times larger than the total amount of all known planetary reserves of finite fossil and nuclear resources (Perez et al., 2011). Solar energy resources are clean, sustainable and distributed around the globe.

Solar photovoltaics (PV) technologies directly convert sunlight to electricity by using semiconductor materials (the word 'photo' means light, while 'volt' is the unit for electric potential). Albert Einstein finalized his famous paper about explaining the photoelectric effect in 1905 (Einstein, 1905), which he won the Nobel Prize in Physics for in 1921. In 1977, Science magazine wrote: "Photovoltaic cells are a space age electronic marvel, at once the most sophisticated solar technology and the simplest, most environmentally benign source of electricity yet conceived" (Hammond, 1977). PV technologies work with direct and diffused sunlight, are operationally reliable, and enable individuals to produce their own electricity.

However, the comprehensive commercial use of solar cells on earth only started in the new millennium. Global cumulative solar PV installations increased from 1.4 gigawatts (GW) in 2000 (EPIA, 2008) to 100 GW at the end of 2012 (Jäger-Waldau, 2013). This rapid market growth has been driven by policies to support solar energy and by steep declines in PV module and system prices. Solar PV has a learning rate of around 22% for modules, meaning that prices have been decreased by 22% for each doubling of cumulative production volume (IRENA, 2013). Thus, PV has the highest learning rate in the energy world (IEA, 2011). The International Energy Agency estimates that the share of PV in global electricity generation will increase from 0.1% in 2010 to 11% by 2050, corresponding to 3000 GW cumulative PV installations (IEA, 2010 a). Moreover, solar PV as a distributed and cost-effective energy source can improve the living standards of those 1.4 billion people lacking electricity (IEA, 2010 b) by providing clean power for lighting, purifying water, and other services (IEA, 2010 a).

However, PV electricity in many countries is not yet competitive with conventional power generation sources, and therefore needs a financing framework with stable returns. Additional justifications to support PV technologies include their substitution for fossil and nuclear energy technologies, and the encouragement of technology development. The world needs effective and efficient policies to unlock the huge energy potential of solar PV. Further PV cost reductions will benefit all countries.

Two countries are of particular importance with their significant policy achievements. On the one hand, Germany has been the largest market for PV installations (cumulative deployment) since 2004 (IEA, 2013), accounting for 32% market share in 2012 (REN21, 2013). On the other hand, China has become the largest manufacturer of solar cells and modules (annual production) since 2007 (Jäger-Waldau, 2013), with a 60% share of cells production in 2012 (IEA, 2013).

The academic literature usually differentiates two categories of policy instruments to support the deployment of renewable electricity sources: price-based mechanisms, like feed-in tariffs, and quantity-based schemes, like tenders or quota systems (Menanteau et al., 2003, Butler and Neuhoff, 2008, Haas et al., 2011). While the remuneration price in a feed-in tariff system is determined administratively by public authorities, tender mechanisms use an auction to determine the required remuneration levels.

Around 72% of the global PV market has been driven by feed-in tariff policies (IEA, 2013). Feed-in tariffs are the most common policy instrument worldwide to support renewable electricity generation, being implemented by 65 countries and 27 states/provinces (REN21, 2012). Germany was the second country (after the United States in 1978) to enact a feed-in tariff policy to support renewable power generation in 1990 (REN 21, 2009) called the Feed-in Law (*Stromeinspeisungsgesetz*, StrEG), and established the Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) with PV specific feed-in tariffs in 2000 (Wüstenhagen and Bilharz, 2006). The respective tariff levels are reduced by specific degression rates to reflect technology learning curves and to ensure that PV technologies will ultimately become competitive with conventional energy sources.

The feed-in tariff mechanism has become the core element in the German strategy to foster the deployment of solar PV. However, as PV system prices decreased much faster than anticipated since 2009, and despite several short-term tariff adjustments in the following years, installation volumes significantly exceeded the governments' annual deployment targets between 2010 and 2012. This development resulted in increasing policy costs borne by electricity consumers, revealed the need for automated responsive feed-in tariff adjustment mechanisms, and raised concerns about the continued suitability of feed-in tariffs for large-scale installations.

1.2 Objectives and research questions

This doctoral thesis aims to contribute to the development and design of effective and efficient policies to remunerate PV power generation. Achieving large-scale global PV deployment and competitiveness, as well as the associated economic and environmental benefits, requires efficient policy schemes to allow for effective deployment, optimal cost reduction and development of industrial manufacturing plants. This paper-based dissertation therefore aims to answer the following research questions:

1. What is the technical potential for different PV technologies in Germany and China and which cost reductions are required for PV to become a competitive electricity source? Who are the industrial actors that can deliver further cost reductions along the production chain, and how are PV industries structured? Which PV policy instruments are used by Germany and China, and what are the respective scales of these policies, to support deployment, investment in new manufacturing plants, as well as research and development?
2. Which factors drive investment choices for new PV installations? How can adjustment mechanisms to price-based remuneration schemes be analyzed and designed? Are feed-in tariffs compatible with policy objectives formulated as installation volumes in specific renewable energy technologies? Which feed-in tariff design can reach deployment targets most effectively?
3. What are the trade-offs to be considered when deciding on the use of feed-in tariffs or tenders to remunerate different scales of solar PV projects? How can the relevant factors impacting deployment and cost effectiveness be quantified?

Paper I (chapter 2) addresses the first research questions with a focus on Germany and China. Paper II (chapter 3) aims at answering the second bulk of research questions by analyzing a unique dataset for the German feed-in tariff system. Paper III (chapter 4) addresses the final research questions by comparing the responsive German feed-in tariff mechanism with tendering schemes in France and other countries.

1.3 Research framework and methods

This thesis applies quantitative and qualitative methods to answer the respective research questions.

Paper I calculates the technical potential of different PV technologies in Germany and China by defining three scenarios of technology development by 2020 (with future deployment dominated by crystalline wafer-based PV, thin film technologies, or multi-junction devices), and by using various estimations of suitable areas, module efficiencies, and electricity consumption. Thereafter, the study calculates PV and coal power generation cost ranges in both countries, as well as the required cost reductions for PV to reach competitiveness, by using data on system prices, lifetimes, maintenance costs, cost of capital, and full load hours for PV, as well as data on fixed and variable costs, and carbon and distribution costs for coal power.

The paper then reviews the industry structure for PV manufacturers and equipment suppliers in Germany and China in 2009, by analyzing the level of concentration and integration across value chain segments. Finally, the paper characterizes the design and implementation of existing PV technology policies in Germany and China and categorizes them into schemes supporting deployment, investment for manufacturing plants, as well as research and development. Moreover, the paper quantifies the respective support scales for each policy category.

Paper II develops an analytic framework to disentangle the various factors driving investment choices in PV installations. Based on a dataset on weekly PV deployment in Germany and quantitative regression analysis considering observed system prices, the analytic model simulates the development of new PV installations and feed-in tariffs for rooftop systems up to 30 kW. The paper uses this model to quantify deployment effectiveness for six policy design options against different price scenarios, in order to systematically define appropriate feed-in tariff adjustment parameters with regard to responsiveness, adjustment frequency, and qualifying periods.

Paper III combines a quantitative evaluation of deployment effectiveness of flexible feed-in tariff mechanisms across PV project scales with qualitative case study research to assess different cost effectiveness dimensions for remuneration through feed-in tariffs and tenders. The paper analyzes investment behavior for small residential and large industrial projects with different project durations. Semi-structured expert interviews with German and French project development companies lead to additional insights about financing and transaction costs in the German feed-in tariff system compared to France and other countries with their tendering schemes.

1.4 Doctoral thesis overview

This dissertation contains three papers which address separate research gaps in the academic literature. These papers are included in the following sections as published or as accepted for publication in the respective journal.

Table 1.1. Thesis overview

	Title	Authors	Journal	Status	Geographic scope	Main research questions	Methods	Selected presentations
I	Survey of Photovoltaic Industry and Policy in Germany and China	Thilo Grau *, Molin Huo, Karsten Neuhoff	Energy Policy 51 (2012) 20–37	Published	Germany, China	What is the technical potential, industry structure, and policy landscape?	Quantitative and qualitative: Techno-economic assessment, country-level case studies	University of Cambridge, United Kingdom; IAEE International Conference, Stockholm, Sweden
II	Responsive Feed-in Tariff Adjustment to Dynamic Technology Development	Thilo Grau	Energy Economics 44 (2014) 36-46	Published	Germany	How can adjustment mechanisms to price-based remuneration schemes be analyzed and designed?	Quantitative: Analytic model to simulate deployment and feed-in tariffs	Tsinghua University, Beijing, China; Conference 'The Economics of Energy Markets', Toulouse, France; EEA ESEM Congress, Gothenburg, Sweden
III	Comparison of Feed-in Tariffs and Tenders to Remunerate Solar Power Generation	Thilo Grau		DIW Berlin Discussion Paper 1363	Germany, France, and other countries	What are the trade-offs for using feed-in tariffs or tenders?	Quantitative and qualitative: Analytic model, semi-structured interviews	Enerday Conference, Dresden, Germany

* Corresponding author. Thilo Grau substantially contributed to the concept, content and methodology of sections 2.1, 2.2, 2.3, 2.4, 2.6 and 2.7. Molin Huo contributed to sections 2.1, 2.2, 2.3, 2.5, 2.6, 2.7, and Karsten Neuhoff contributed to sections 2.1, 2.2, 2.7.

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2 Survey of Photovoltaic Industry and Policy in Germany and China

Thilo Grau [a,*], Molin Huo [b], Karsten Neuhoff [a]

- Published in Energy Policy 51 (2012) 20-37 -

Abstract

Photovoltaic (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 survey policies in Germany and China and the industrial actors they can encourage to pursue innovation, including deployment support, investment support for manufacturing plants and R&D support measures. 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.

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2.1 Introduction

Photovoltaic (PV) technologies have rapidly developed in recent decades, with system prices falling by 52% between 2006 and 2011. However, in contrast to several recent IT developments, most of the new investments in the PV sector are still pursued with government support. On the one hand, this situation poses a challenge, because it creates regulatory uncertainty and requires continued public support. On the other hand, this also represents an opportunity, because the public policy decision to support PV can be the basis for a comprehensive PV innovation strategy combining R&D programs, support for innovative production technologies and deployment schemes. The focus of this paper is on the international dimension of the challenge through the lens of two countries with strong stakes in the development, China and Germany.

First, we explore the motivation for governments to support PV by calculating the technical potential for different technologies in both countries (section 2.2.2-2.2.3). We find that building-integrated solar cells alone could meet around one third of the electricity demand projected for 2020 in Germany and China. This potential provides a strong motivation to advance the technology for both countries. We calculate the required cost reductions for PV to become a competitive electricity source in Germany and China (section 2.2.4). While China offers a larger technical potential with its higher solar radiation rates in many provinces, there are potentially also lower costs to compete against, as environmental externalities of coal are not yet addressed in the wholesale power price. Thus for both countries further cost reductions of PV will be essential to realize its large-scale energy potential. A variety of cost reduction opportunities from innovative cell designs to optimization of manufacturing processes are listed in the literature, and can – going by the track record of the industry during recent years – contribute to significant further technology improvements (section 2.2.5).

We therefore explore, in a second stage, the actors that can deliver these cost reductions and technology improvements (section 2.3). While both industry and public research laboratories play a crucial role, the scope of the paper is limited to industrial actors. We find that while manufacturing capacities are higher in China, more of the equipment is supplied by German companies. The level of concentration and vertical integration within the manufacturing industry is similar in both countries. With regard to equipment suppliers, there are both dedicated firms that have grown with the technology, and firms that have expanded their activities and brought along their expertise from related industries. This industry characteristics and structure will determine how government policy can impact on the innovative performance in the sector.

We therefore characterize in sections 2.4 and 2.5 the policy instruments used by the German and Chinese government to support deployment, investment in new production capacity, and R&D. We find that deployment support schemes have become extensively used and succeeded in enabling PV projects and delivering cost reductions. A gradual growth of demand creates continued investment in new manufacturing plants and growing markets for innovative equipment suppliers.

We find that both Germany and China are interested in the success of large-scale PV electricity supply, as they are interested in low-cost and sustainable power supply as well as increased security of energy supply. PV technology will work on a large scale if costs are halved. This requires further innovation. Thus, a key question for national and international policymakers is: how can a common global vision of PV as an essential future environmental technology provide the guidance for design and implementation of national PV technology policies? We find that:

First, the values of R&D support schemes are small relative to the amount of deployment support in both countries.

Second, PV manufacturers benefit directly (and equipment suppliers indirectly) from investment support measures for manufacturing plants, including grants, interest-reduced loans, reduced taxes and public guarantees. However, we find that investment support for manufacturing plants is not sufficiently linked to requirements to explore the application of innovative cell and manufacturing concepts in either Germany or China.

Third, the public policy debate with regard to PV is increasingly focusing on national industrial policy objectives. In Germany, actors are increasingly concerned that the large PV deployment program of the feed-in tariff 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.

Understanding the mutual concerns and respecting both the need for global increasing markets and for participation in the products is essential for both parties. The national deployment programs of countries like Germany and increasingly China have been essential for the creation of a consistently growing global market for PV. Thus, these programs have allowed for the development of internal expertise and attracted firms across different industrial sectors to provide their resources and skills to unlock PV cost reduction potentials. A stable further development of the global demand – and therefore a few more years of public deployment support programs – are essential to retain and further develop this expertise and innovation networks in the sector, so as to allow them to deliver the objective of both China and Germany to reduce the costs of PV as a key energy technology.

2.2 Photovoltaics: Technical potential and cost reduction potential

2.2.1 Historical development of PV installations and production

Figures 2.1 and 2.2 show the historical development of annual PV installations and world PV cell/module production. While Germany has become the largest PV market, China has become the largest producer of cells and modules.

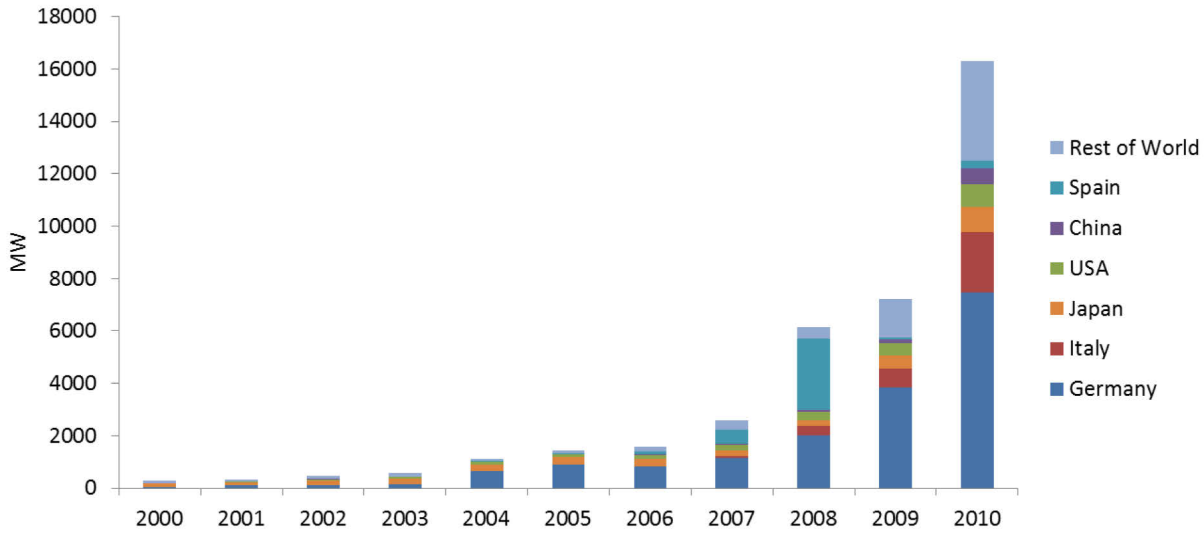

Figure 2.1. World Annual Photovoltaic Installations

Sources: IEA PVPS, 2010; EPIA, 2008; EPIA, 2010; REN21, 2011; NDRC, 2007; China Sustainable Energy Project Reference Material; Renewable Energy Law Implementation Assessment; GSE data; www.solarbuzz.com .

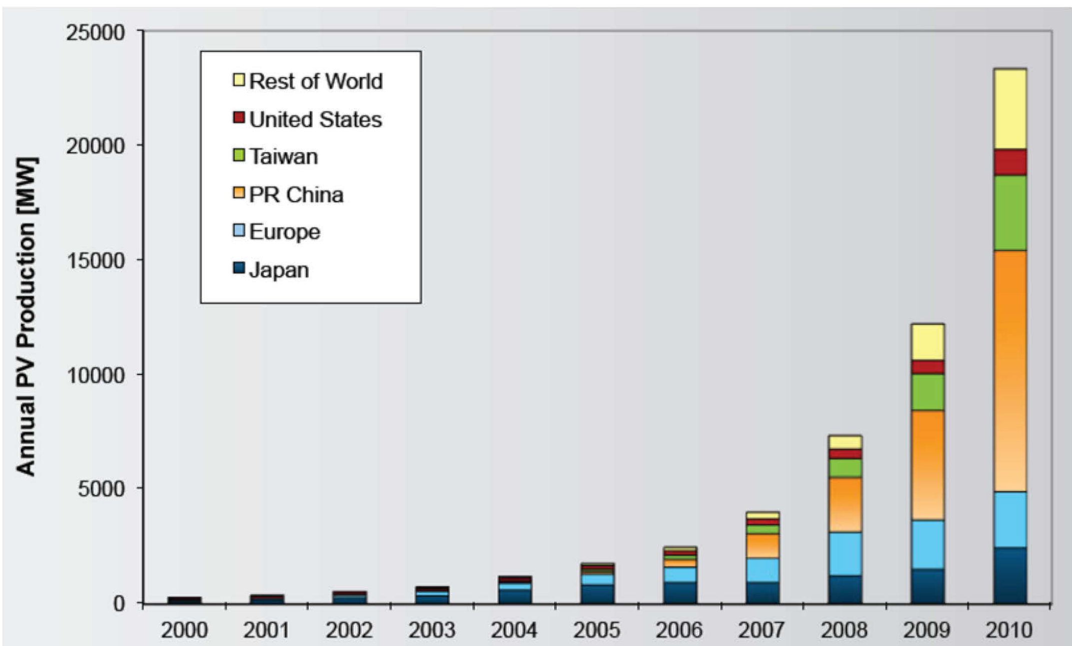

Figure 2.2. World PV Cell/Module Production

Source: EC, 2011.

2.2.2 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 that surface area requirements are higher (due to lower efficiency), for non-silicon based approaches some input materials are rare elements (e.g. tellurium (Te)), and other materials (such as Cadmium (Cd)) can represent a hazard for human health.

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

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

*** Standard testing conditions

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

Several ideas for new cell designs have been proposed in the past to reduce costs or increase efficiencies. They 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-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.

2.2.3 Technical potential of photovoltaics for different 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 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).

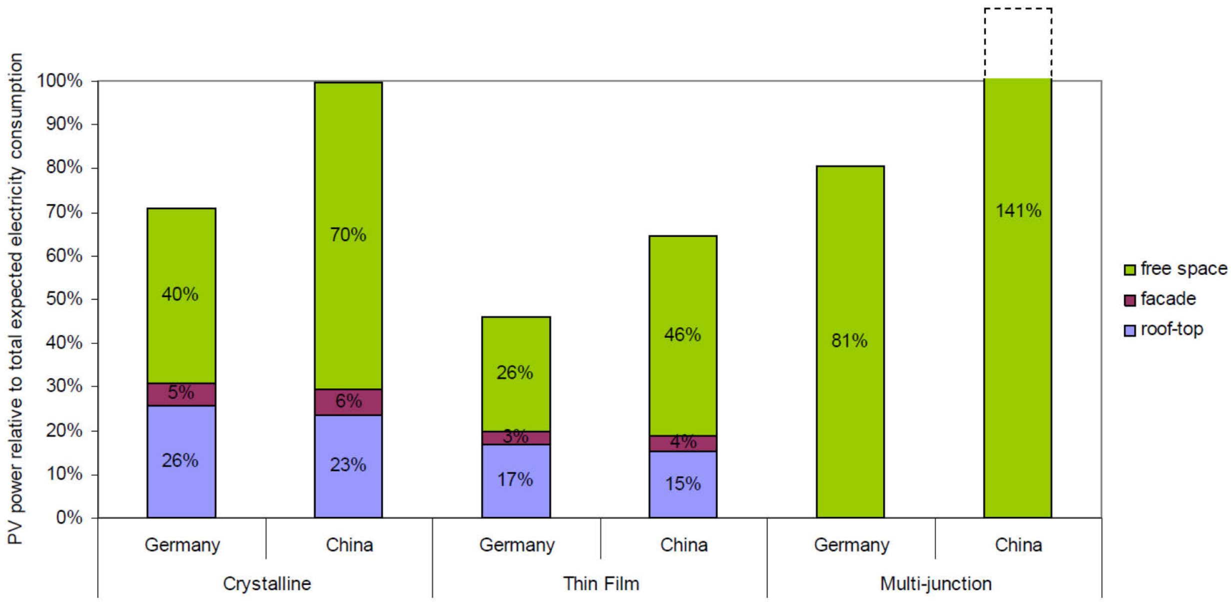

Figure 2.3. PV technical potential 2020 in Germany and China based on different technology choices

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.

2.2.4 Cost and price development of PV

The cost of PV has demonstrated a fascinating development over the last decades, having 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.

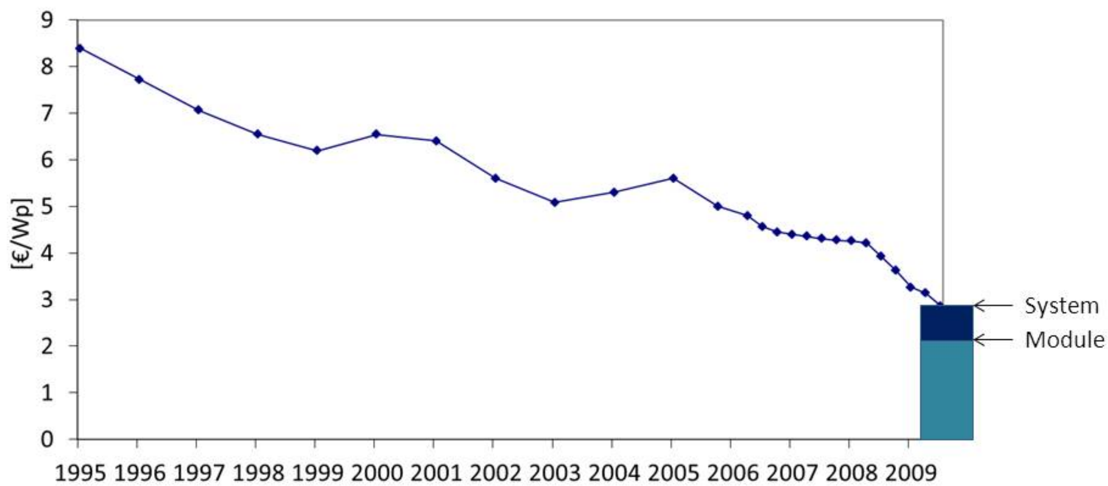

Figure 2.4. Trend in PV (roof-top) system prices in Germany

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

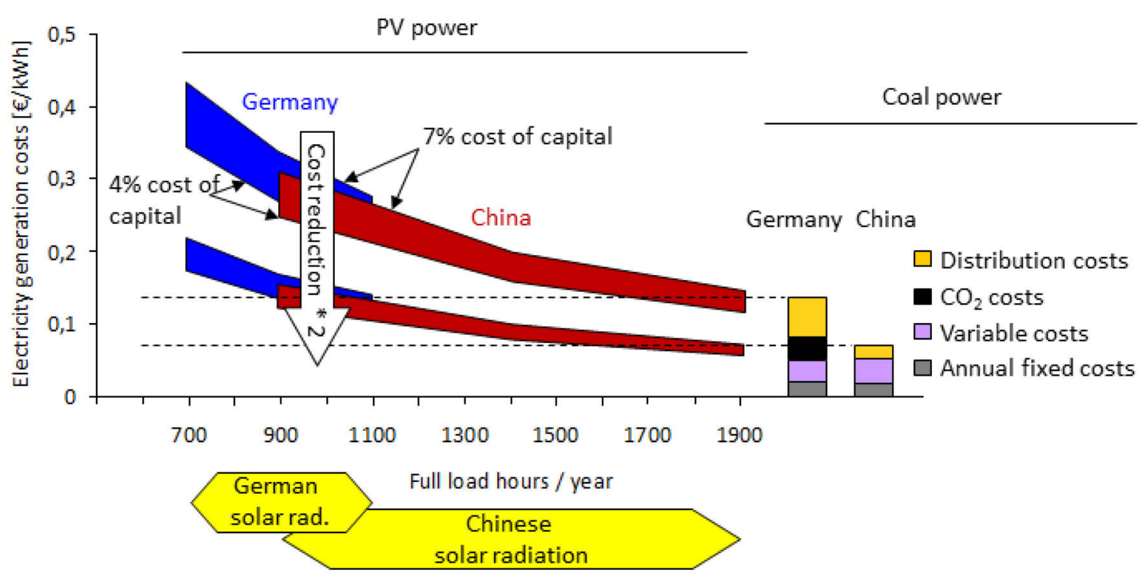

Figure 2.5. PV and coal power generation costs

(Based on PV system prices during the third quarter of 2010).

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. A significant share of the costs - €55/MWh - relate to the distribution network and metering. PV installations can replace the need for distribution network expansion, e.g. to meet power demand of air-conditioning or growing residential needs, and in such instances savings exceeding €55/MWh. In many cases in Germany, distribution costs are fixed as distribution networks are sufficiently strong and sunk – in these instances private actors might save distribution costs on their electricity bill, but there is likely to be less impact on system cost savings. 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.

2.2.5 Photovoltaic value chain with cost reduction potentials

The (crystalline) PV production chain covers four production stages, Ingot, Wafer, Cell and Module.

Table 2.2. Production chain with cost shares and technology improvement opportunities

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%	

(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). The table also illustrates 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. 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 which might pursue the necessary technology improvements and cost reductions to reach competitiveness for photovoltaics.

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

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

2.3.1 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 2.6 shows the biggest PV manufacturers in Germany, with their respective capacities in 2009, along the (crystalline) PV production chain.

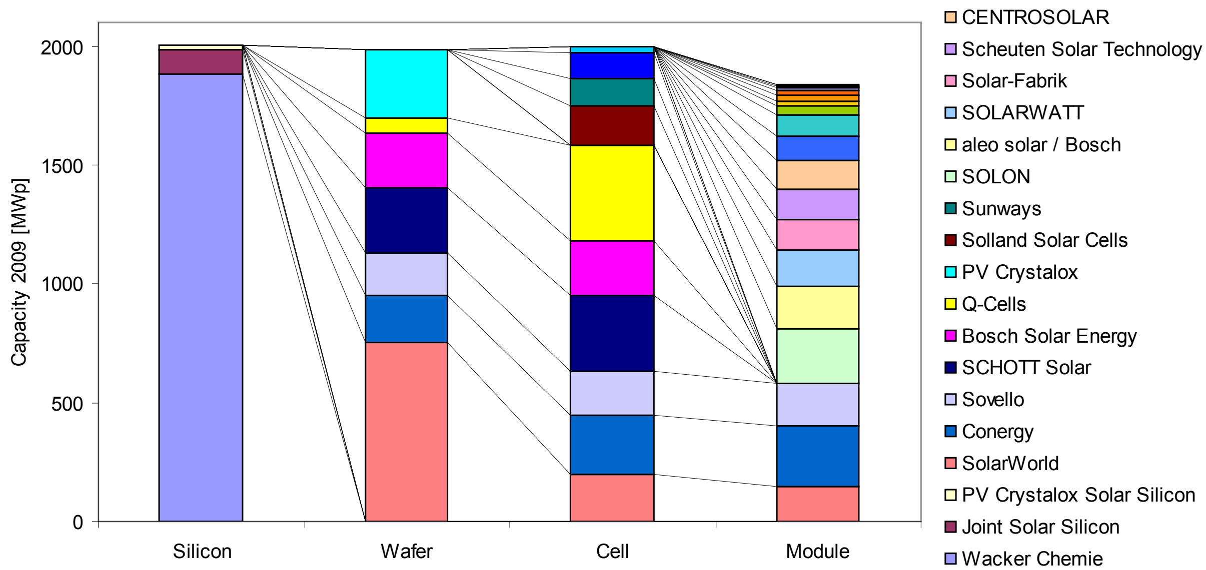

Figure 2.6: PV manufacturers in Germany along production chain.

(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 investment requirements and less knowledge-intensiveness required. There are also fully integrated companies combining wafer, cell, and module manufacturing, such as SolarWorld, Conergy and Sovello.

Figure 2.7 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.

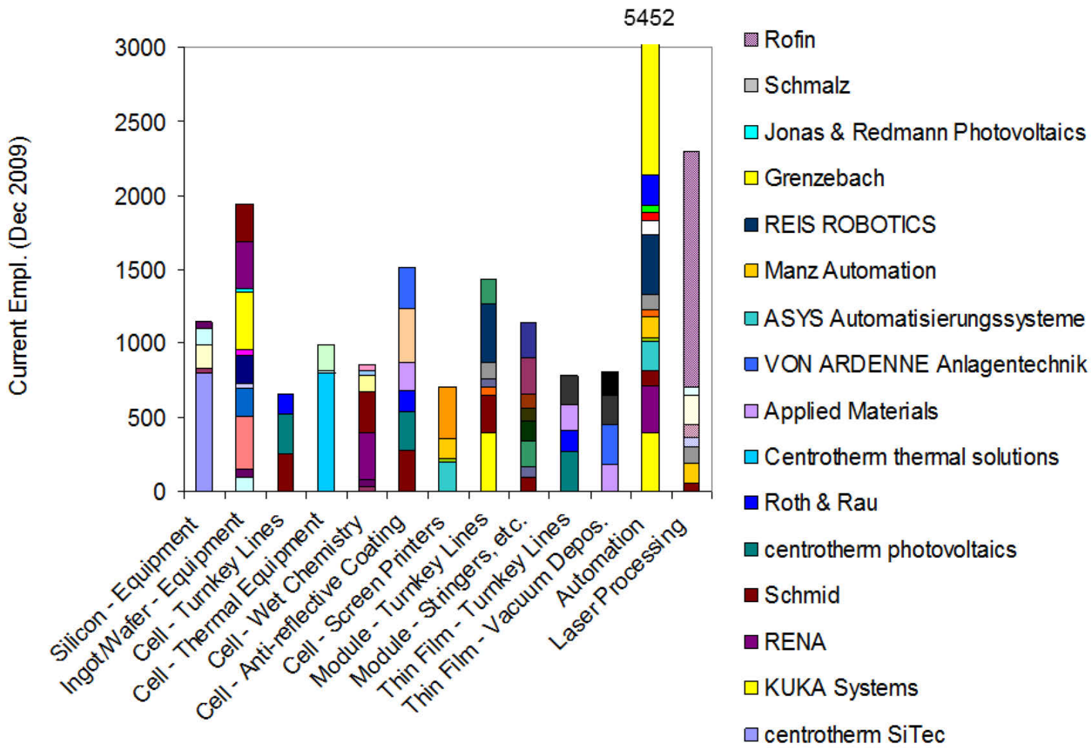

Figure 2.7. PV equipment manufacturers in Germany

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

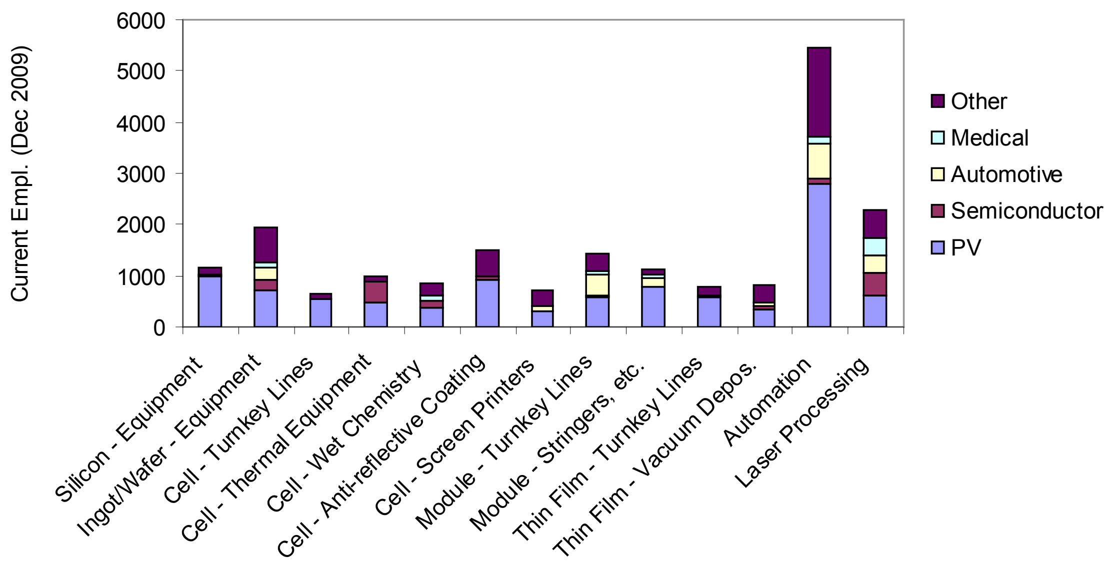

Figure 2.8. PV equipment manufacturers in Germany – sector background (activity in sectors). (Based on data from GTAI (2009b))

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 2.8 shows the activities of equipment manufacturers in the related semiconductor, medical, and automotive industries.

2.3.2 Industry structure in China

In each sector, we surveyed the large manufacturers which account together 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). These manufacturers are depicted in Figure 2.9.

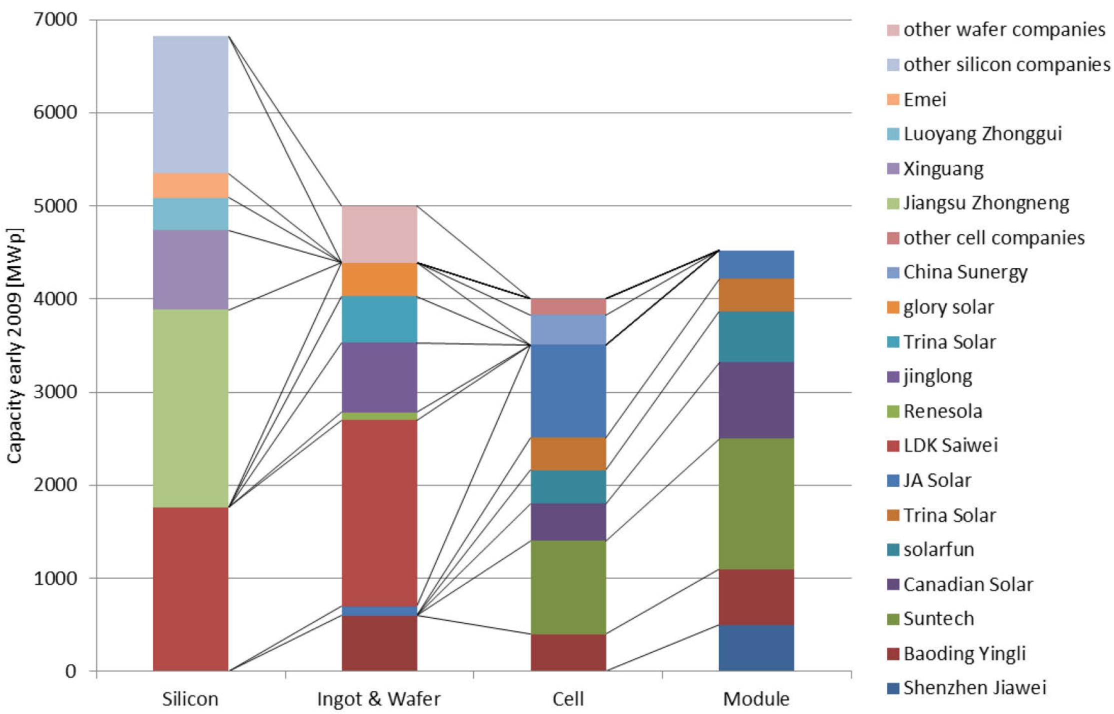

Figure 2.9. PV manufacturers in China along production chain

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

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. The silicon capacity grew fast from 2008 to 2009, so that the capacity in 2009 for polysilicon was higher than for other components. However, as these production lines were still being calibrated and tested, the silicon production in 2009 was relatively small and China still relied on importing silicon. Most polysilicon manufacturers were not integrated with other components because innovation capacity and intensive investment are required to sustain improvement. Now big wafer manufacturers are starting to integrate polysilicon production so as to assure material supply. The biggest integrator in China, Yingli, integrated wafer, solar cell and module assembly from 2004, and just commissioned a polysilicon facility in December 2009[1] whose production capacity is 3000 metric tons per year. The biggest wafer manufacturer in China[2] 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.[3] In September 2009, GCL initiated a wafer production branch in Jiangsu Province, which acquired the biggest polysilicon manufacturer in China, Jiangsu Zhongneng.[4]

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, a lot of big cell producers have established their own module production line.

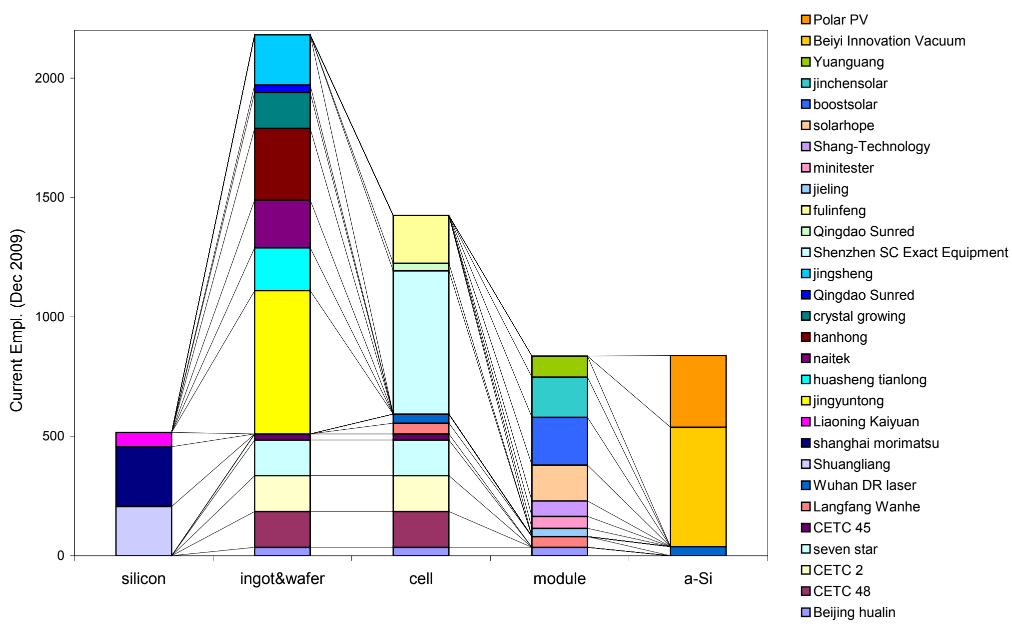

Figure 2.10. PV equipment manufacturers in China

(Source: Company websites)

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

We analyzed the largest equipment suppliers by their number of employees for each segment of the production chain (Figure 2.10 covers three silicon, twelve ingot/wafer, ten cell, nine module, and three thin-film equipment suppliers). Figure 2.10 shows that the greatest integration is between equipment supply of ingot/wafer and cell equipment supply: there are five companies in this category. The figure also shows Wanhe, which supplies equipment for cell and module, and Wuhan, which offers DR laser supply for cell and a-Si.

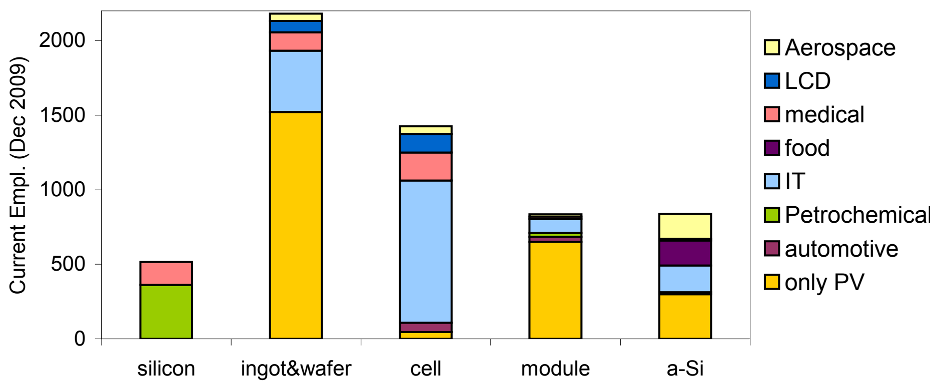

Figure 2.11. PV equipment manufacturers in China – sector background (activity in sectors) (Source: Company websites)

Figure 2.11 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.

2.3.3 Summary and comparison of industries

Within the PV industry, the most notable contrast is that production capacities for PV manufacturing are higher in China, while more of the manufacturing equipment is supplied in 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 as important as it is in PV, the mix of segment specialists and vertically 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 integration across the value chain, while policies that target specific segments may reinforce the segment specialists, particularly in those segments receiving support. Whether either or both of these two 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 segments 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.

2.4 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 2.12 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.

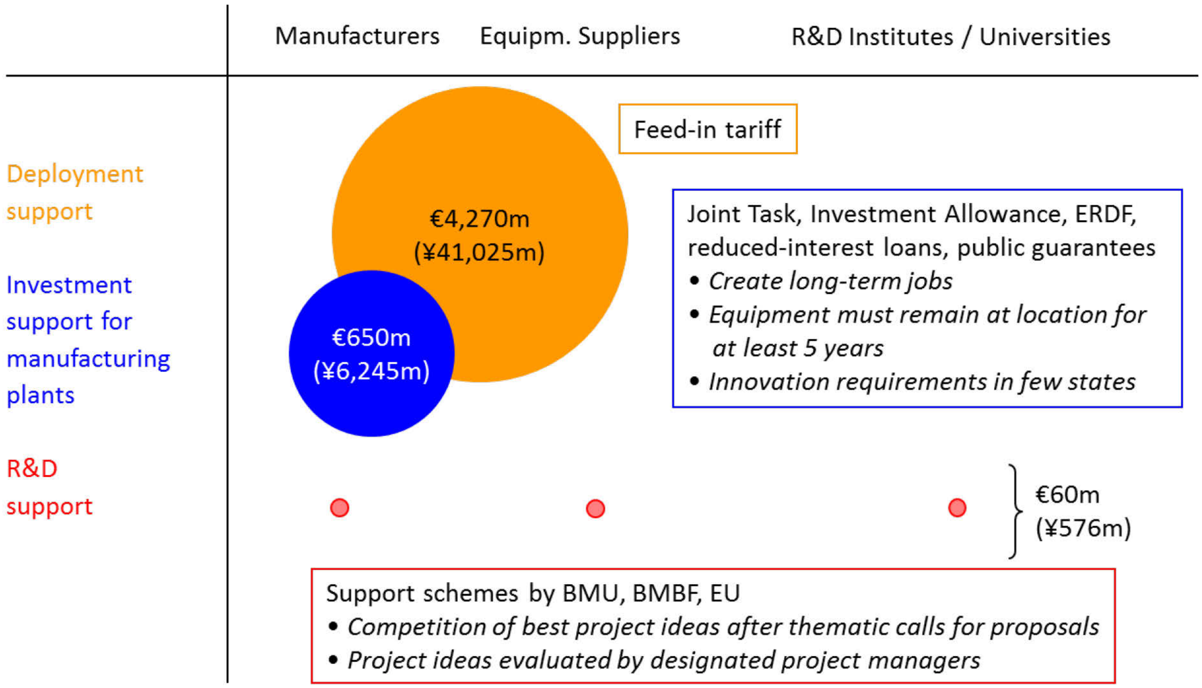

Figure 2.12. PV support measures in Germany (with main criteria applied to allocate support) and their target groups.

2.4.1 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 2.3 gives an overview of the recent German PV feed-in tariffs.

Table 2.3. PV feed-in tariffs according to German EEG

		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

Sources: (EEG, 2008; BMU, 2010b; BNetzA, 2010b).

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 additionally to cut back the feed-in tariff in July 2010 and October 2010, as shown in Table 2.3. 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[5] per year on average. New PV installations increased strongly in 2004 and 2009 (see Figure 2.1), after the PV feed-in tariff was raised in 2004, and after system prices decreased strongly in 2009. The total system expenditure for PV installations represented this development in the respective periods, as shown in Figure 2.13.

[5] 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.

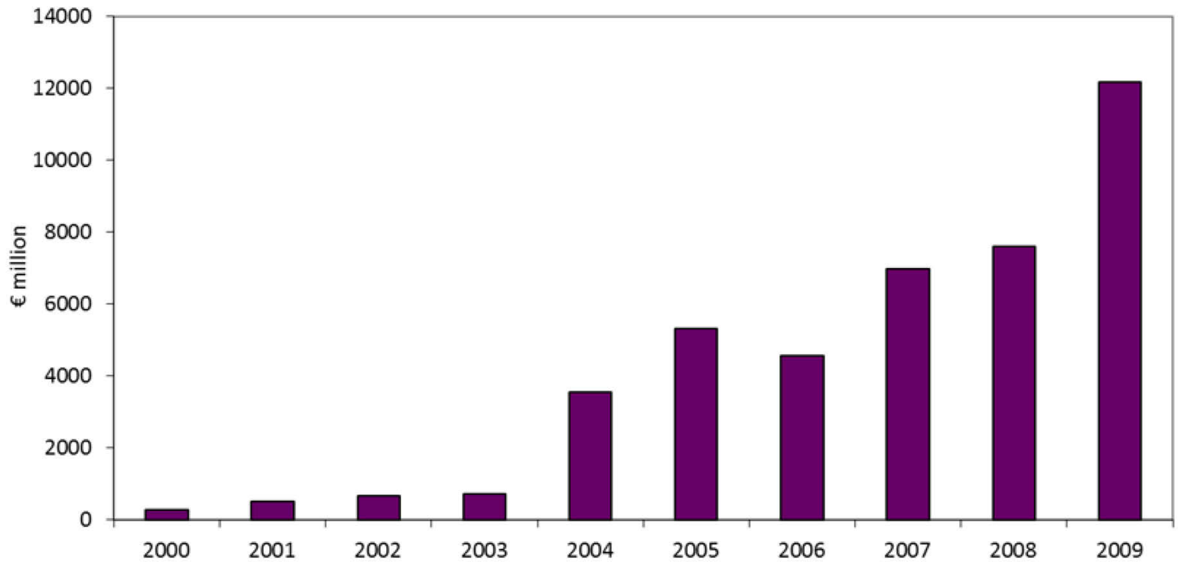

Figure 2.13. Total system expenditure for PV installations in Germany

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

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.

2.4.2 Investment support for manufacturing plants in Germany

Germany offers different investment incentive programs which can be categorized into three groups:

- 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 incentives program. Specific criteria within each program determine individual investment incentives rates. 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, because that is the typical scale of PV manufacturers (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).

a) Grants / Cash Incentives

There are two major cash incentives programs offered in Germany: 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. Incentives rates vary between different regions according to their stage of economic development. The regions with the highest incentives levels (period 2007-2013) are clustered in the eastern parts of Germany – they offer subsidy rates of e.g. up to 30 percent of eligible project costs for large enterprises. Some regions in Western Germany (except the states of Baden-Württemberg and Hamburg) also offer grants – e.g. up to 15 percent of eligible expenditures for large companies.

While a general program requirement is the creation of long-term jobs by the investment project, eligible investment amounts are up to €500,000 per job created. Most manufacturing and service industries are eligible, with eligible project costs being (direct) investment costs or (future) operating costs.

Figure 2.14 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 2.8), 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.

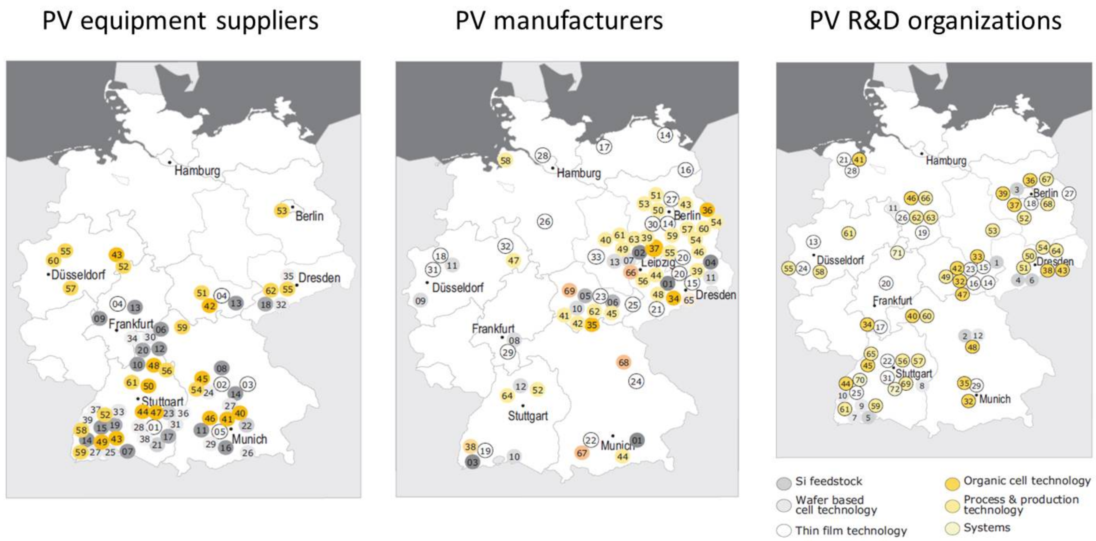

Figure 2.14. Geography of PV manufacturers, equipment suppliers, and R&D organizations in Germany

(Sources: GTAI 2010a, GTAI 2010b, GTAI 2010c)

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

The IZ program promotes 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, InvZulG 2010). The IZ is usually allotted in the form of a tax-free cash payment. Promotion rates for large enterprises amounted to 12.5% for investments started in 2009, and decrease each year by 2.5% (until 2013 with a rate of 2.5%). The respective promotion rate applicable at the start date of the project will be received for the duration of the complete project. While there are no limits concerning the investment amount, a general requirement is the remaining of the subsidized equipment at the investment location for at least five years. Most manufacturing and certain service industries are eligible. Funding will automatically be received if all eligibility criteria are satisfied (without any application procedures).

Investment Allowance funds and Joint Task grants can be combined up to the maximum possible Joint Task regional incentives level. 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 IZ (automatically) and 20 percent from GRW 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 2.14 (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

To facilitate financing investment projects through the capital market, companies lacking securities may apply for public guarantees. There are different types of public guarantees available to secure bank loans in Germany. They can cover up to 80% of the individual loan amount (GTAI 2010d). The investor has to submit the application for a guarantee to the respective mandatory (e.g. state development bank) via his commercial bank.

2.4.3 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 on collaborative projects;
- development risk and implementation time; and
- the possibility to spread research findings, while considering the protection of findings through patents.

Table 2.4 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.

Table 2.4. Newly approved PV funding from BMU

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%

(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. The European Union's main instrument for funding research in Europe is the Seventh Framework Programme for Research and Technological Development (FP7). This program runs from 2007 until 2013.

2.5 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," made by the National Development and Reform Commission (NDRC) in 2007. The official PV installation targets are 5 GW by 2015 and 20 GW by 2020. The experience and outcome of these policies is therefore a crucial 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. Figure 2.15 shows the expenditure scale of each policy. Euro prices were based on the exchange rate on July 1, 2009. R&D incentives have the smallest budget at both federal and regional levels.

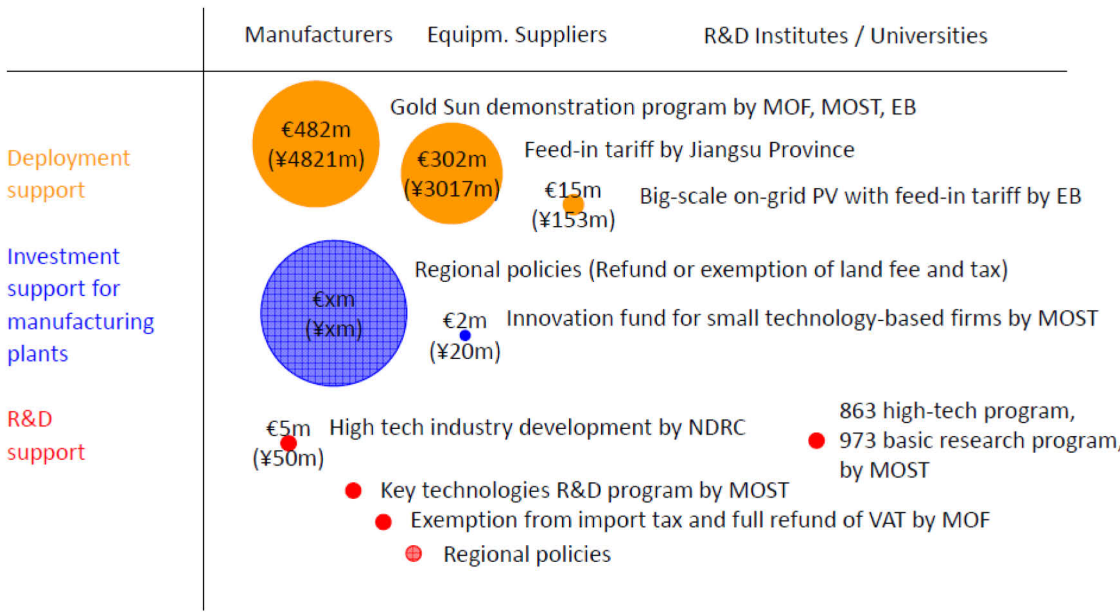

Figure 2.15. PV support measures in China in 2009

2.5.1 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. This means that the competitive tender selected both the investor and the equipment supplier, since the investor and the equipment supplier are colaborated together to submit a 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 area (¥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) BIPV and BIPV demonstration project by MOF and MHURDC

The first phase started in March 2009 and included 111 projects with a total capacity of 91 MWp. This project supplies a maximum ¥20/Wp for building material integrated PV and a maximum ¥15/Wp for rooftop- and façade-installed PV. The second phase started in April 2010 including about 99 projects with 90.2 MW. The subsidy for BIPV and BAPV was ¥17/Wp and 13 ¥/Wp to the capital investment respectively.

c) Concession bidding feed-in tariff for large-scale on-grid PV projects, sponsored by NEA

The National Energy Administration (NEA) initiated a feed-in tariff with concession bidding for large-scale on-grid PV projects in China. The feed-in tariff level was mostly chosen by bidding. However, if a large-scale on-grid PV project "A" locates near another project "B" which has a feed-in tariff already, the project "A" might be provided the same feed-in tariff as "B", without bidding. In 2008, a 1 MW project in Shanghai's Chongming Island and a 255 kW project in Eerduosi city, Neimenggu province 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 this bidding-based feed-in tariff.[6]

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.

With the same methodology we used to calculate the public expenditure of the German 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[7] 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

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 to be on rooftops. The feed-in tariff is fixed for 25 years but the level of FIT 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 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. We therefore use the average solar radiation, 5000 MJ/m^2 every year. We assume that the

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

discount rate is 8%. Thus the present value of total alternative public expenditure in 25 years is ¥3017.4 million (constant=2009).

2.5.2 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,[8] there was about ¥20 million to support PV projects in 2009.

Table 2.5. 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; This 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 got loan from banks; no more than 500 employees; This 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;

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

- employees who had education beyond college level must account for not less than 30% of total employees;
- the total number of R&D employees must not be less than 10% of staff; and
- annual R&D investment of the applicant must not be less than 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 take them as examples. Table 2.6 provides an overview of these policies, further details can be found in Huo and Zhang (2012).

Table 2.6. Policies of local governments

Refund of loan interest	(Huaian) Refund equal to 50% of the real interest of loans only in the year when most equipment was bought, if the initial investment is more than €50 million. (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.
Refund of electricity consumption fees	(Huaian) Refunds equal to ¥0.05/kWh or ¥0.1/kWh in the first year of production, depending on manufacturing capacity.
Refund of land transfer fee	(Huaian and Jinzhou) Refund of the residual land transfer fee, if the initial investment in PV manufacturing is more than €50 million.
Refund of corporate income tax	(Huaian) New plants can be refunded 100% of residual corporate income tax from the first to the second year, and 50% from the third to the eighth year.
Refund of value added tax payment	(Huaian) New PV plants can receive 50% of the residual VAT payment from the first to the second year, and 25% from the third to the fifth year. (Jinzhou) New PV plants can receive 100% of the residual VAT payment from the first to the third year, and 50% from the fourth to the sixth year.

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 2.16, 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 2.17

shows, the refund of corporate income tax is the largest part of the subsidy, while the refund of VAT payment is the second largest.

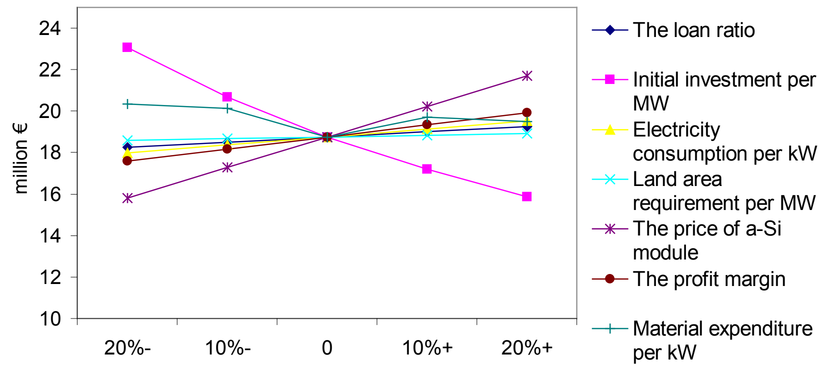

Figure 2.16. Sensitivity analysis of regional subsidies

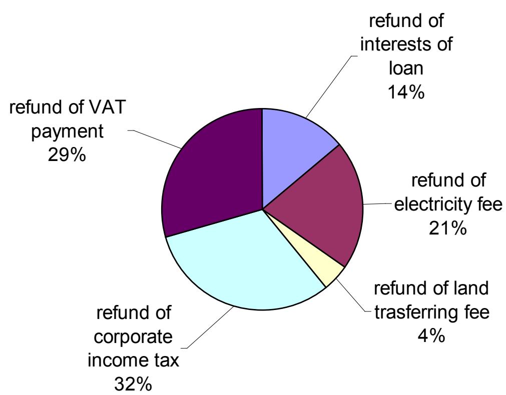

Figure 2.17. The structure of regional subsidies

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].

2.5.3 R&D support in China

a) MOST: High-tech Program 863; Basic Research Program 973; Key Technologies R&D Program

The People's Republic of China's Ministry of Science and Technology (MOST) has a budget to support R&D in research institutions and firms, in order to assist with every "Five Year Plan" issued by the federal government. There are three kinds of programs to support PV R&D (see Figure 2.18), described below (see also Huo and Zhang, forthcoming):

Figure 2.18. PV R&D supporting programs of MOST.

- MOST's National High-tech R&D Program (Program 863) supports innovation in strategic high-tech fields. The program was created in 1986. It has disbursed funding to R&D of BIPV, CPV, on-grid large-scale PV in deserts, and thin-film, from 2006 to 2010;
- MOST's Chinese National Basic Research Program (Program 973) supports basic scientific research for long-term development. It was founded in 1997. Between 2006 and 2010, it gave €3 million to thin-film R&D projects;[9]
- MOST's Key Technologies R&D Program supports R&D for the current development of the national economy. It was created in 1981 and, during the period 2006-2010, has disbursed funds for R&D of C-Si technology and equipment.

The approach of the program is to provide non-repayable cash, based on R&D contracts.

There are some staffing and organizational criteria for program participation. Using Program 863 as an example (MOST 2007), applicants had to satisfy the following criteria:

[9] http://www.973.gov.cn/ReadItem.aspx?itemid=604

- The director has to: be younger than 55 years, a senior researcher or with a PhD degree; have a good record over the past three years; be leading only one project in this program within a five-year period;
- The research institution or firm must have: research expertise and experience in the specific sector; professional R&D employees; shown that development of specific technology or equipment is feasible.

The selection procedure is as follows. MOST asks a consulting group of academic experts to undertake planning for the program, including identifying specific R&D projects to support and for which to budget. When MOST publishes plans, any company or research project may apply for a specific project within the program by submitting a feasible plan. MOST then calls for experts to evaluate applications in which they have particular expertise, in order to achieve transparency and equity.

Some criteria for assessing and selecting recipients of funding are:

- innovation;
- significance;
- feasibility;
- research conditions;
- financial feasibility.

Various examples covering different actors can be provided:

- PV manufacturers: Xinguang had one R&D project in the Key Technologies R&D Program from 2006 to 2010. MOST supplied €600,000 for research and development of a key technology in polysilicon production;
- equipment suppliers: Nanjing Chunhui and Chengdu Zhongshun jointly received support for one R&D project through Program 863 from 2006 to 2010. MOST supplied €2.9 million in total for research and development of equipment for the Concentrated Photovoltaic system on the megawatt level. The companies were required to invest at least €2.9 million at the same time;
- research institutes: the China Academy of Sciences and Nankai University received support for one Program 973 project in the period 2006 to 2010. MOST supplied ¥30 million for basic research of low-cost and long-life thin-film PV cell;
- PV developers: Shanghai Solar Technology company received support for one Program 863 project from 2006-2010. MOST supplied ¥20 million for applied research of BIPV on-grid system on the megawatt level. The company was required to invest at least ¥40 million in the project.

b) NDRC National High-tech Industry Development Program

This National Development and Reform Commission (NDRC) program in 2005 targeted R&D development and demonstration projects for manufacturers and R&D institutions (NDRC, GEF, 2006). The cumulative expenditure on PV R&D was around €5.02 million.

The program's approach

For an incentive that is between ¥30 and ¥200 million and less than 50% of total project, the applicant can receive a non-repayable investment subsidy or non-repayable subsidized loan interest. If the incentive is ¥30 to ¥200 million and more than 50% of the total project, the applicant can receive a capital infusion.

The criteria defining whether projects are eligible are (NDRC 2006):

- project planning is feasible and has social and economic benefits; R&D and demonstration are market-oriented;
- the company has financial resources and the capability for developing technology; the applicant also finances more than 30% of the project;
- construction project receives land use and environment protection approvals;
- the applicant will secure independent intellectual property rights.

The selection procedure is as follows. The NDRC asks an independent expert pool or consulting institution to evaluate applications. The NDRC then makes a selection, according to the evaluation results and recommendations of its experts.

The criteria for the selection of funding recipients include:

- the technology of the project is innovative;
- the project will lead to upgrading of related industries;
- the owner of the project has the capability to operate and to develop the technology;
- the project will get market feedback and economic benefits;
- the project plan is feasible.

c) Exemption of import tax and VAT for R&D institutions by MOF

This policy is issued by the Ministry of Finance, General Administration of Customs, State Administration of Taxation (MOF 2009), with an implementation period between 1 July 2009 and 31 December 2010.

- when foreign-invested R&D institutions import equipment and instruments, companies can benefit from exemption from import tax and related VAT;
- when foreign-invested or domestic R&D institutions buy domestic equipment, they get a full VAT refund.

The qualification criteria for those who can receive funding are:

- investment centers of foreign investment established before 30/09/2009:
  - R&D investment expenditure: For foreign-invested R&D institutions less than two years old, the total investment is at least US$5 million. For an R&D department or branch, the total investment is at least US$5 million. For foreign-invested R&D institutions more than two years old, the total R&D expenditure is at least US$10 million;
  - R&D employee: at least 90 full-time R&D employees;
  - cumulative equipment expenditure from the beginning is at least ¥10 million.
- investment centers with foreign investment established after 01/10/2009:
  - R&D investment expenditure: for an independent legal entity, R&D department or branch, the total investment is at least US$8 million;
  - R&D employee: at least 150 full-time R&D employees;
  - cumulative equipment expenditure from the beginning is at least ¥20 million.

d) Regional R&D support policies

In 2009, some Chinese city governments issued incentives to promote R&D by PV manufacturers, using city government and/or city council finances. In Huaian (Huaian 2009), after a senior technical employee has worked for a PV manufacturer for one year, he or she can receive a subsidy from local government. Individuals with a Ph.D. get ¥1000 every month; individuals with senior titles get ¥800; individuals with a master's degree or vice senior title get ¥600 every month. In Yangzhou city, in the same province as Huaian (Yangzhou 2005), if a PV manufacturer creates a research institution which is honored as a national research institution, provincial research institution or postdoctoral center, it gets an award from local government. For the national research institution title, the award is ¥200 million, and for the provincial research institution title, the award is ¥100,000.

2.6 Comparison of PV policy in Germany and China

Table 2.7 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.

Table 2.7. PV support measures in Germany and China

	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 State Development Bank Loans) Public Guarantees (State / Federal)	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. 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 program, 973 program, 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)

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

2.6.1 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 was 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 modules (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 module 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 and 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 installations 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.

2.6.2 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.

2.6.3 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 having been 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, see section 2.5.3].

2.6.4 Global policy coordination

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. Attempting formally to coordinate national programs might create delays that would risk the commercial viability of equipment suppliers, cell manufacturers and project developers.

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 2009-2011 and, to maintain overall support for the German renewables policy, the scale of support dedicated to German PV deployment will be reduced in 2012. 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 deployment support to the level of 893 MW PV installations by the end of 2010 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.

2.7 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 in many locations still the most expensive form of commercial 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 exploration of improvement opportunities and the search for alternatives by individual actors. 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, the level of concentration and integration across segments of the PV value chain and between PV manufacturers and equipment suppliers is analyzed.

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. 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 deployment program of the feed-in tariff 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. On 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 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 provide the guidance for design and implementation of national PV technology policies?

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3 Responsive Feed-in Tariff Adjustment to Dynamic Technology Development

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Abstract

This paper reviews the adjustments of the feed-in tariffs for new solar photovoltaic (PV) installations in Germany. As PV system prices declined rapidly since 2009, the German government implemented automatic mechanisms to adjust the remuneration level for new installations in response to deployment volumes. This paper develops an analytic model to simulate weekly installations of PV systems of up to 30 kW based on project profitability and project duration. The model accurately replicates observed market developments and is used to assess different adjustment mechanisms against multiple scenarios for PV system price developments. The analysis shows that responsive feed-in tariff schemes with frequent tariff adjustments and short qualifying periods reach deployment targets most effectively.

JEL Classification: O30, O31, Q42, Q48, C60.

Keywords: feed-in tariff, solar photovoltaic, renewable energy deployment.

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3.1 Introduction

Renewable energies like solar photovoltaics (PV) can provide multiple benefits to societies, like reducing greenhouse gas emissions, improving energy security and energy access, and fostering economic development (Mitchell et al., 2011). Governments around the world use various policies to meet their targets to reduce greenhouse gas emissions and to increase the renewables' share in final energy consumption. While a carbon price high enough to effectuate the innovation needed to deal with climate change cannot be credibly implemented (Fischer and Newell, 2008), technology policy in combination with mitigation incentives can help to reach environmental goals faster and more efficiently (Fischer, 2008). Economic justifications to support renewable energies include their substitution for fossil fuel technologies with environmental externalities (carbon dioxide emissions), and the positive learning by doing externality.

There are different policies to directly support the deployment of renewable energy technologies, like feed-in tariffs or quota requirements for electricity generation, to promote investments for manufacturing plants as well as for research and development. Rivers and Jaccard (2006) account for learning by doing for clean energy technologies and show that, while regulatory policies are more expensive than market-based instruments, they may be superior when evaluated considering additional criteria like effectiveness, political acceptability, and administrative simplicity. While Lehmann and Gawel (2013) show that renewables support schemes are needed to achieve sufficient levels of technology development due to market and policy failures, and to address additional policy objectives like security of energy supply, Benthem et al. (2008) illustrate that most benefits of the solar policy in California can be allocated to a correction of the learning by doing externality.

Feed-in tariffs are the most common policy instrument worldwide to support renewable electricity generation, having been implemented by 65 countries and 27 states/provinces (REN21, 2012). In Europe, 21 out of 27 EU member states used feed-in tariff schemes as major support instruments in 2011 (Kitzing et al., 2012). Feed-in tariffs have become attractive as the guaranteed off-take price facilitates low-cost financing and administrative procedures for renewable energy deployment. According to the European Commission, "well-adapted feed in tariff regimes are generally the most efficient and effective support schemes for promoting renewable electricity" (Commission of the European Communities, 2008, page 3). By comparing feed-in tariff, quota and auction mechanisms to support wind energy development in the UK and Germany, Butler and Neuhoff (2008) show that the German feed-in tariff in practice resulted in more deployment and lower prices paid per wind power delivered. Bürer and Wüstenhagen (2009) focus on private investors in innovative clean energy technology firms, and show that they perceived feed-in tariffs to be the most effective renewable energy policy. Couture and Gagnon (2010) provide an overview of different feed-in tariff remuneration schemes and conclude that market-independent, fixed price models (like the German feed-in tariff) create greater investment security and lead to lower-cost renewable energy deployment than market-dependent options.

The German Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) guarantees technology-specific tariffs for electricity feed-in generated by renewable energies. These tariffs are differentiated by energy source (solar, wind, etc.) and provide a purchase guarantee for a contracted time period (usually 20 years). The respective feed-in tariffs are reduced by specific degression rates and reviewed every three or four years to promote technology improvement and to ensure that renewable energy technologies will ultimately become competitive with conventional energy forms. Feed-in tariff levels for solar photovoltaics (PV) were revisited every four years until 2009. While the German National Renewable Energy Action Plan (Bundesrepublik Deutschland, 2010) defines a deployment target of 52 gigawatt (GW) installed PV capacity in 2020, the newly agreed version on the amended Renewable Energy Sources Act (EEG 2012) from June 2012 defines an annual target corridor between 2.5 GW and 3.5 GW for new PV installations.

However, in recent years PV system prices declined significantly faster than expected, thereby increasing profitability for investors and triggering large investment volumes exceeding governments' annual deployment targets. Since 2009, deployment volumes significantly exceeded target volumes, turning Germany into the largest PV market in the world in 2009, 2010 and 2012 (accounting for 32% of global cumulative PV installations in 2012). Therefore, an automatic adjustment mechanism dependent on ongoing deployment volumes was introduced in 2009 in order to match PV system price reductions, followed by further adjustments to the mechanism in 2010 and 2011. Nevertheless, the deployment volume again reached around 7.5 GW of new annual PV capacity in 2011 and 2012 (see Figure 3.1). This development is seen as a challenge, as the higher volumes increase the policy costs borne by electricity consumers, and thus raised concerns about the continued suitability of feed-in tariffs. With regard to Germany's feed-in tariff degression framework, Kreycik et al. (2011, page 17) find that "uncertainties still remain over whether responsive degression frameworks can control policy costs to the degree desired by policymakers".

This leads to the research question for this paper: Are feed-in tariffs compatible with policy objectives formulated as investment volumes in specific renewable energy technologies? The paper uses an analytic framework that allows for the disentanglement of the various drivers of this dynamic market development. The analytic model introduced in this paper simulates the evolution of new PV installations and feed-in tariffs for systems of up to 30 kW on the basis of observed PV system prices. This model is based on only three factors: (i) deployment increases proportionately with project profitability; (ii) profit expectations of investors decreased over time; and (iii) in periods prior to feed-in tariff reductions, projects are implemented more quickly in order to still receive the higher tariff levels.

The experience of the last years shows that deployment volumes can be explained by these simple factors. Therefore, the model is used to test five policy design proposals against different price scenarios in order to systematically define appropriate PV feed-in tariff adjustment parameters. Model results show that responsive feed-in tariff mechanisms with frequent tariff adjustments and short qualifying periods reach deployment targets effectively for small-scale systems with short project durations.

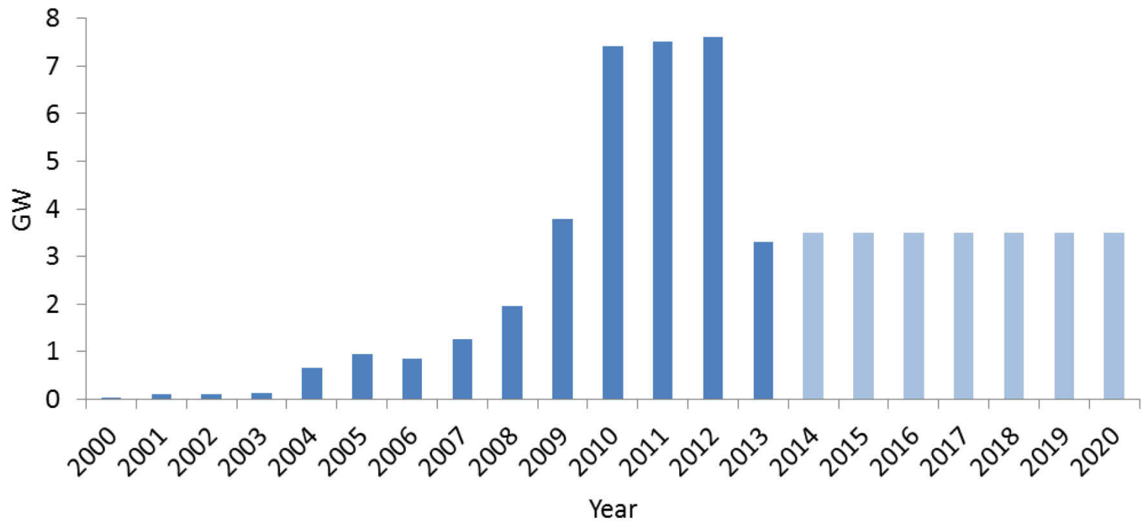


Figure 3.1. Annual PV installations in Germany 2000-2013, with targets until 2020

Sources: Data from BMU (2012), BSW-Solar (2014), and Bundesrepublik Deutschland (2010).

In the following, Section 3.2 traces the historic evolution of PV system prices and support level adjustments in Germany, and shows the responsiveness of PV deployment to feed-in tariff levels. Section 3.3 provides an analytic framework to explain the drivers for the observed behavior. Section 3.4 describes the data and parameter choices for the model. Section 3.5 uses the analytic framework to assess different policy design options under various price scenarios. Section 3.6 concludes the paper with a recap of findings.

3.2 PV technology development and feed-in tariff adjustments

3.2.1 Historic evolution of PV system prices

PV system prices have undergone a surprisingly rapid reduction since 2009. Figure 3.2 shows that prices for rooftop systems of up to 10 kWp decreased by 66% in Germany since 2006. System price declines accelerated since 2009, with the period between 2009 and 2012 showing the strongest annual price declines.

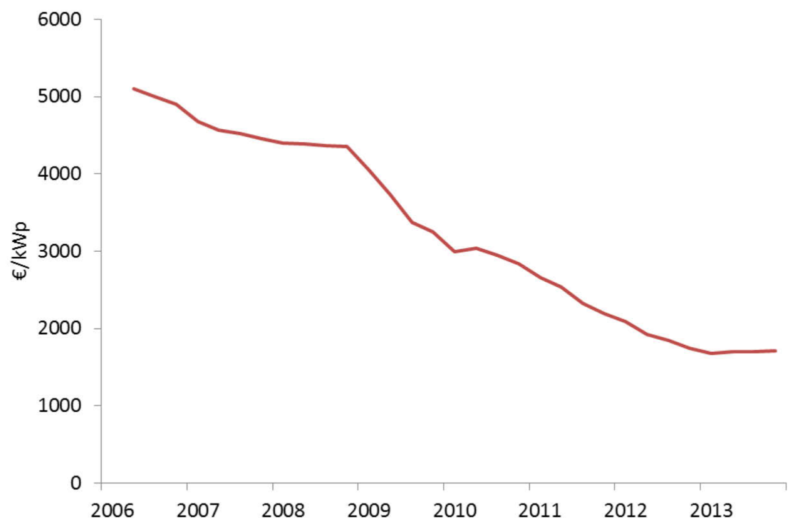


Figure 3.2. Prices for installed rooftop PV systems of up to 10 kWp

Note: Prices shown are average net prices without value added tax.

Data sources: BSW-Solar (2013a) and BSW-Solar (2013b).

3.2.2 History of PV feed-in tariff adjustments in Germany

The Renewable Energy Sources Act (EEG) was established in Germany in 2000, succeeding the Electricity Feed-in Act from 1990. It regulates feed-in tariffs for renewable electricity generation. The feed-in tariffs within the EEG are differentiated by energy source (solar, wind, etc.), and are usually guaranteed for a period of 20 years. The respective tariff levels for new installations are traditionally reduced by annual degression rates and are reviewed every three or four years, thus creating the incentive for manufacturers to improve technologies in order to ensure that renewables will become competitive with conventional electricity generation in the future.

In light of the dynamic cost developments of photovoltaics, anticipating PV system prices is challenging. If the degression rate is set above the innovation potential, feed-in tariffs may become too low to allow for an economic deployment of further renewable technologies. Given the share of the German market in the global situation, this was interpreted as a high risk for the further development of the technology and the industry. Setting degression rates too low can lead to windfall gains for manufacturers or project developers, and deployment volumes that exceed initial plans can cause significant cost increases.

The first PV feed-in tariff was established in 2000 at a rate of 0.99 DM/kWh (approximately 0.51 €/kWh), and the annual degression rate was originally set at five percent. Since 2004, tariffs have been graded according to system capacity and installation type (rooftop, façade, and free-standing installations), with rates between 0.46 and 0.62 €/kWh. From 2006 onwards, the annual degression rate for field installations increased to 6.5 percent. Since 2009, there are four tariff categories for rooftop installations (≤ 30 kW, 30-100 kW, 100-1000 kW, > 1000 kW), which were adjusted in June 2012 (≤ 10 kW, 10-40 kW, 40-1000 kW, 1-10 MW).

With the amendment of the EEG in October 2008 (EEG 2009), a "breathing cap" was introduced for new PV installations in order to allow the tariff level to respond to deployment volumes on an annual basis (annual 2009 target corridor: 1 to 1.5 GW). The EEG 2009 increased the annual base degression to eight percent for rooftop systems of up to 100 kW and to ten percent for other systems. Additionally, the degression rate should be either reduced or increased by one percent if PV deployment falls below or above the yearly target corridor.

In 2009, PV system prices declined by 26 percent (much more rapidly than originally expected), leading to total deployment of 3.8 GW. It became clear that the flexible degression adjustment was too weak. Therefore, the EEG was amended in August 2010, implementing additional tariff reductions between 8 and 13 percent on 1 July 2010, and three percent on 1 October 2010. The newly established degression system had the objective to deliver a target corridor of 2.5 to 3.5 GW annual installations. The base degression rate of 9 percent was set to increase by up to four percent if deployment exceeded this target volume. As annual PV installations amounted to 7.4 GW in 2010, feed-in tariffs were reduced accordingly by 13 percent on 1 January 2011.

The EEG Amendment from April 2011 implemented a new mechanism with the following biannual PV feed-in tariff adjustments dependent on the rate of deployment: (i) on 1 July 2011 by up to 15 percent[10]; (ii) and on 1 January 2012 by a base degression of 9 percent, with an additional adjustment of between -7.5 and 15 percent. The possible annual degression rate could therefore be between 1.5 percent and 24 percent[11].

However, this mechanism did not result in any degression in July and September 2011 (as less than 875 MW was installed between March and May 2011), and led to a 15 percent degression in January 2012 (as 5.2 GW were installed between October 2010 and September 2011).

The EEG 2012, passed by the *Bundestag* (Lower House of German Parliament) in June 2011, defined that the valid PV feed-in tariff degression scheme was to continue. According to the German Federal Network Agency (*Bundesnetzagentur*), Germany set a new monthly record of three GW installations in December 2011, resulting in 7.5 GW annual deployment in 2011. This motivated calls for further tariff adjustments. A draft version of a newly amended feed-in tariff mechanism was released in March 2012, but blocked in the *Bundesrat* (Upper House, representing the federal states) in May.

In June 2012 the German government finally released the agreed version on the revised PV feed-in tariff policy, including a one-off tariff reduction on 1 April 2012, ranging from 20 to 29

[10] For ground-mounted systems on 1 September 2011.
[11] When determining the new degression rate on 1 January 2012, the advanced "interim" degression from 1 July 2011 would be taken into account.

percent for new installations.[12] Between May and October 2012, tariff levels were continuously reduced by 1 percent on a monthly basis. From November 2012 onwards, PV feed-in tariff degression levels depend on deployment, are adjusted every three months and implemented on a monthly basis.[13] This adjustment mechanism aims to deliver an annual deployment corridor between 2.5 GW and 3.5 GW until 52 GW cumulative PV capacity will be reached.

3.2.3 Weekly PV deployment and market responsiveness

To improve monitoring of market development, since January 2009 new PV systems must be registered at the Federal Network Agency (*Bundesnetzagentur*). Although these systems are categorized according to their date of registration, and not their date of commissioning, the data allows for a realistic assessment of actual market volume (Reichmuth 2011).

Figure 3.3 shows weekly PV installations and feed-in tariff levels in Germany since January 2009. In periods prior to a reduction of the feed-in tariff, the volume of PV installations increased as house owners and project developers still wanted to benefit from the higher tariffs.

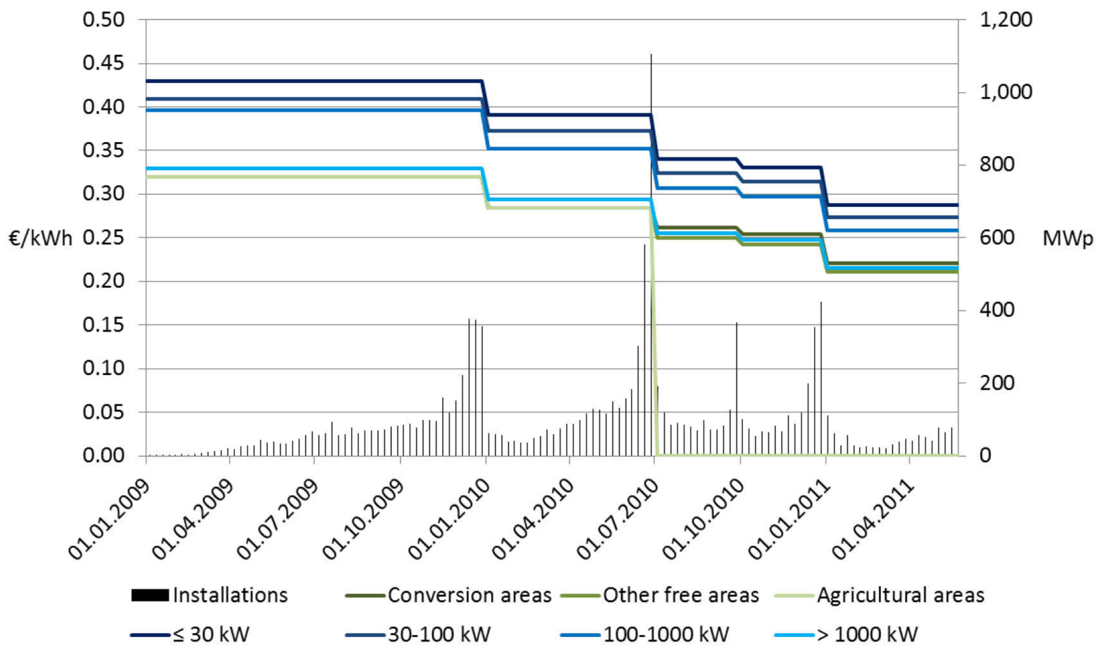


Figure 3.3. Weekly PV installations and feed-in tariff levels in Germany between January 2009 and May 2011

Installations based on data from *Bundesnetzagentur*.

[12] The law came into force on 1 April 2012. It includes new categories for rooftop systems, while ground-mounted systems receive a uniform tariff. Installations above 10 MW receive no further tariffs.

[13] The adjustment of the feed-in tariff on 1 November 2012 depends on deployment in the period July until September 2012, projected on a yearly basis. The calculation of the degression levels from 1 February 2013 and 1 May 2013 onwards is based on the following qualifying periods: July until December 2012 and July 2012 until March 2013 respectively (projected on a yearly basis). From 1 August 2013 onwards, the degression will depend on deployment in the respective previous 12 months. The Federal Network Agency has one month to determine deployment and new feed-in tariff rates. If installations stay considerably below the target corridor, the degression will be paused or tariff levels will even be increased.

These characteristic demand peaks can be observed in all relevant sub-categories, as shown in Figure 3.4. However, market responsiveness of these categories varies. Larger projects are usually more responsive to changing support schemes, if we compare PV deployment within the last week (or the last two weeks) before a feed-in tariff reduction to cumulative installations within the whole period of the same feed-in tariff levels. For instance, PV deployment was three times higher during the last two weeks of 2009 than the annual average for systems of up to 30 kW, five times higher for systems between 30 and 100 kW, eight times higher for systems between 100 and 1000 kW, and seven times higher for installations above 1 MW.

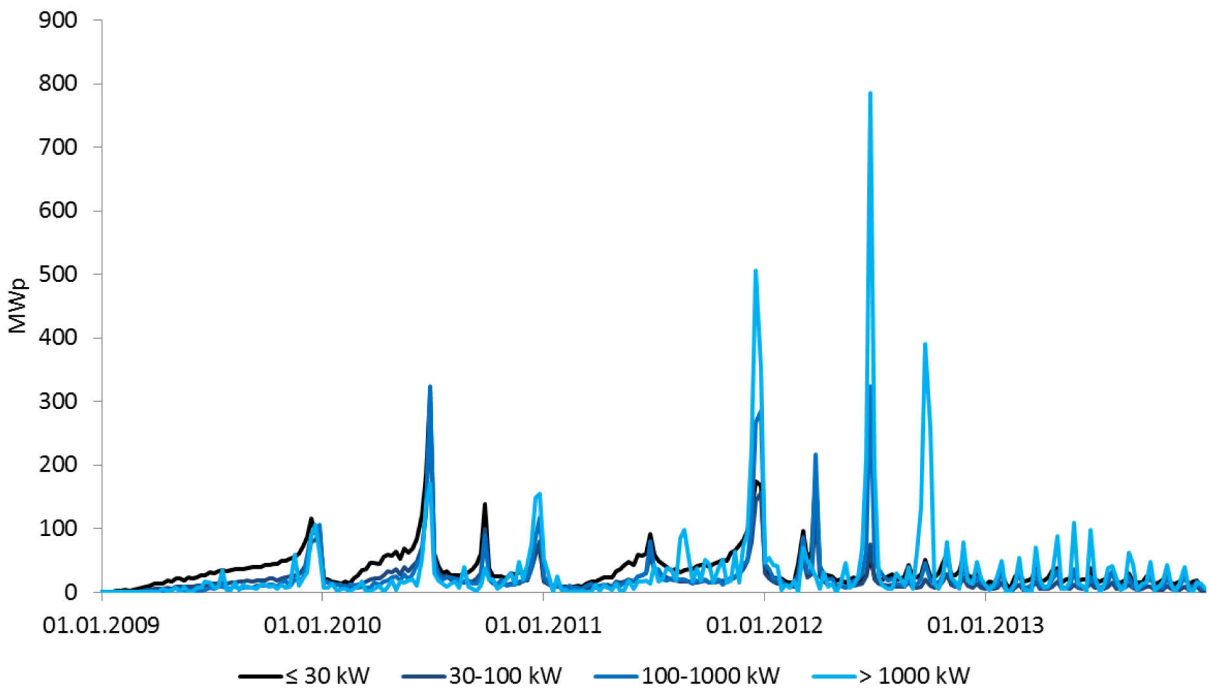


Figure 3.4. Weekly PV installations for relevant size categories in Germany between 2009 and 2013

Based on data from *Bundesnetzagentur*.

This work focuses on the small-scale rooftop category of up to 30 kW of the German PV feed-in tariff, as installations up to 30 kW accounted for 35%, 31%, and 23% of total installations in Germany in 2010, 2011, and 2012 respectively. Weekly deployment of PV systems of up to 30 kW is shown by the dark curve in Figure 3.4.

3.3 Analytic framework

The deployment effectiveness of a feed-in tariff scheme is analyzed using a simple model. The model depicts three factors impacting deployment. First, deployment increases proportionately with project profitability. Second, profit expectations of investors decreased over time. Third, deployment is responsive to feed-in tariff changes. In periods prior to feed-in tariff reductions, project implementation accelerates to still receive the higher tariff levels.

3.3.1 Basic model

The basic model (without simulation of demand peaks) is as follows. The analysis considers a discrete-time economy. At the beginning of every period t, each household decides whether to invest in a PV project, that would be finalized at date $t+d$, taking into account the average project duration d. PV installations Y_{t+d} at time $t+d$ depend on profits π_{t+d} according to the function

$$Y_{t+d} = \alpha * \pi_{t+d} - c, \tag{1}$$

with parameters α and c. To account for increasing interest and changing profit expectations of households over time, both parameters α and c can be determined for different time periods.

Profits of PV projects are defined as net present value:

$$\pi_{t+d} = v_{t+d} - p_t \tag{2}$$

where p_t is the average system price at date t and v_{t+d} is the present value of the feed-in tariff at time $t+d$.

The present value v_t of the feed-in tariff is given by the equation:

$$v_t = f_t * h * \sum_{j=0}^{n} (1+i)^{-j}, \tag{3}$$

where f_t is the feed-in tariff at date t, h is the amount of full load hours per annum, n is the amount of years which the feed-in tariff is paid for, and i is the annual interest rate.

3.3.2 Advanced model with peak simulation

To account for the characteristic demand peaks of historic PV market evolution (see Figure 3.4), the basic model is extended as follows. The assumption is that, in periods before the feed-in tariff is reduced, investors make use of the flexibility to accelerate project execution so as to still qualify for the higher tariff levels. This market behavior then leads to the observed “clearance sale” effects. The representative investor chooses the project duration d_t at time t according to the function

$$\begin{gathered} d_t = \max l \\ subject\ to\ \pi_{t+l} \geq \pi_{t+d_{ave}} \\ d_{min} \leq l \leq d_{ave}, \end{gathered} \tag{4}$$

where d_{min} and d_{ave} are the minimum and average project duration respectively. While projects are usually implemented within the average duration, implementation accelerates in periods prior to feed-in tariff reductions.

Thus, the volume of PV installations at date $t+d_{ave}$ is given by the equation:

$$Y_{t+d_{ave}} = \sum_{\substack{-\infty \leq m \leq \infty \\ if\ (m+d_{t+m}=d_{ave})}} (\alpha \pi_{t+d_{ave}} - c) \quad (5)$$

3.4 Quantitative evaluation and parameter choices

For the purpose of this model, a period t corresponds to one week. PV modules can achieve around 900 full load hours per year on average in Germany, and the feed-in tariff is paid for a time period of n=20 years. Annual interest rates i are based on monthly data published by Deutsche Bundesbank (2014).

The overall process duration of PV projects depends on system sizes. In Germany, according to PV GRID (2014), it varies between 5 to 10 weeks (7 weeks on average) for small-scale systems on residential buildings, 5 to 15 weeks (9 weeks on average) for medium-scale installations on commercial buildings, and 24 to 53 weeks (40 weeks on average) for large-scale industrial ground-mounted plants on open lands. To calculate profits of small-scale rooftop systems, the model uses their average project duration of 7 weeks.

The analytic framework is based on price and interest rates data available at the beginning of 2014. Photovoltaik-guide (2014) provides monthly PV system price data between January 2009 and January 2014 for installations ≤ 100 kW. To use price data for systems ≤ 30 kW, the data is adjusted with a fixed shift factor.[14] Figure 3.5 shows the evolution of profits, as well as system prices and present values of feed-in tariffs (calculated based on a fixed 3.5% interest rate).

[14] This shift factor is calculated based on data from IEA (2011).

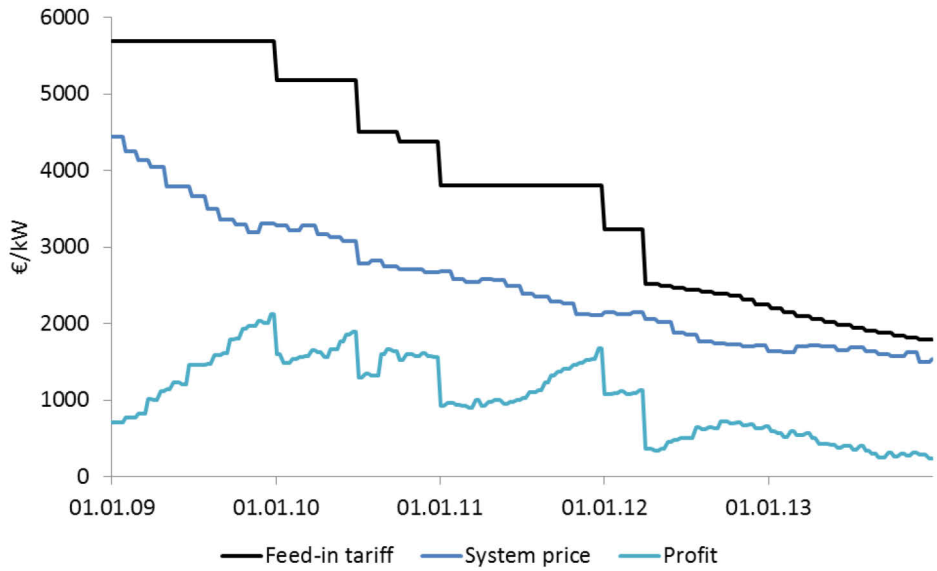
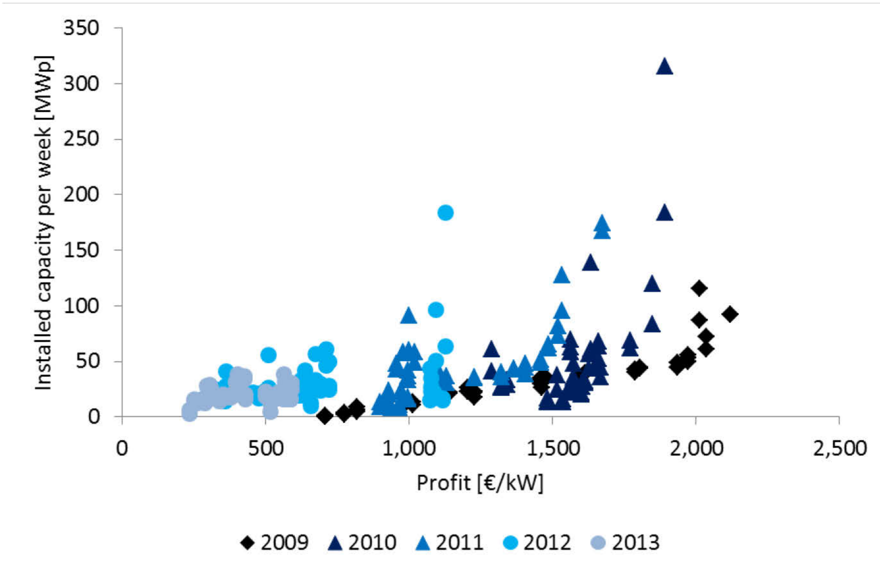


Figure 3.5. PV feed-in tariff, system prices, and profits for solar panels of up to 30 kW in Germany between January 2009 and December 2013

To analyze the first two factors (see section 3.3), Figure 3.6 shows the relationship between historic PV installations and profits (margins to cover risks like e.g. the failure of components during 20 years of lifetime). The amount of weekly installations largely increases with rising profits. However, there are several outliers, which represent "clearance sale" effects in weeks before the feed-in tariff was reduced. Moreover, this figure illustrates that the relationship between installations and profits has shifted over time. Compared to previous periods, lower margins are needed for the same amount of installations in later periods, meaning that profit expectations of investors have decreased over time. A maturing market with increasing experience and decreasing risk for project developers, social bandwagon effects, as well as increasing environmental awareness and motivation of households to invest into clean energy sources might be reasons for this shifting investment behavior. These observations validate the first two factors of the model.



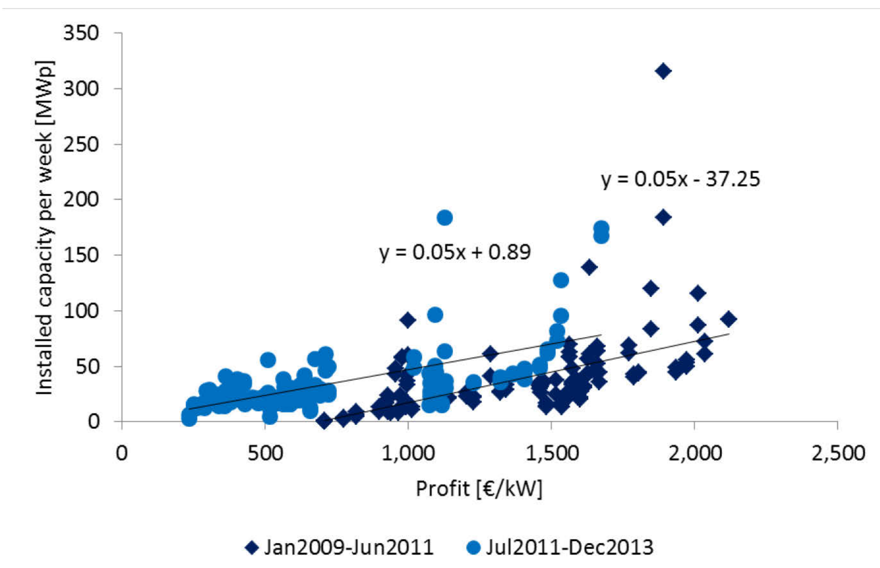


Figure 3.6. Weekly PV installations and profits for systems of up to 30 kW in Germany, 2009-2013

The analytic framework assumes a linear correlation between weekly installations and profits in Germany. To adjust for changing investment behavior and maturing market conditions over time, the model considers two aggregated historic time periods as shown in Figure 3.6. Quantitative estimations lead to the parameters α_1=0.05 and c_1=37.25 for January 2009 until June 2011, as well as α_2=0.05 and c_2=-0.89 for July 2011 until December 2013. Compared to the period before June 2011, lower margins are needed for the same amount of installations from July 2011 onwards. The recent correlation between installations and project profitability is assumed to stay constant in later periods.

Based on these parameters, Figure 3.7 shows the resulting evolution of PV installations according to the basic model (see section 3.3.1). The framework could also be based on alternative functional relationships between deployment and profit levels. A logarithmic functional form is considered in the appendix.

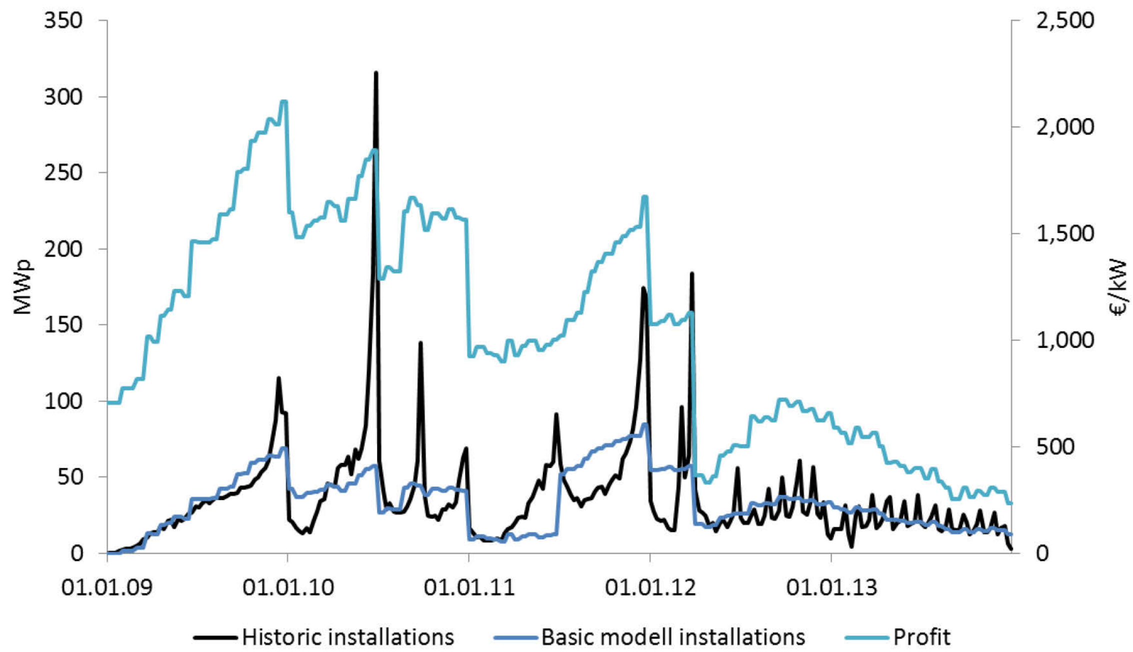


Figure 3.7. Historic and model-based weekly PV installations (basic model) for systems of up to 30 kW

The basic model delivers a relatively realistic match of historic and model-based installations. However, the largest deviation to historic PV deployment is the demand peaks observed in periods before feed-in tariff reductions. The advanced model (see section 3.3.2) is used to simulate these peaks.

In comparison to large ground-mounted PV projects, private investors with small-scale residential systems are able to more closely time their investment decisions in response to price changes. According to PV GRID (2014), for small residential systems investors need to schedule two weeks at most for the administrative process, between two to five weeks for obtaining a grid connection permit, and between one and five weeks for grid connection and commissioning.

As mentioned above, the overall process duration of PV projects in Germany varies between 5 to 10 weeks for small-scale installations on residential buildings. The basic model uses the average project duration of 7 weeks to calculate profits of roof-top systems of up to 30 kW. However, project developers have an interest in accelerating the implementation process in periods prior to feed-in tariff reductions. Therefore projects which are started 5 to 6 weeks before a feed-in tariff reduction are implemented more rapidly, so as to be completed in the last week before the tariff cut.

In the next section, this advanced model is used to simulate PV deployment between January 2009 and December 2016 for different feed-in tariff designs and system price scenarios.

3.5 Model results

3.5.1 Results for the current adjustment mechanism

In this section, the advanced model (see section 3.3.2) is used to simulate weekly PV deployment for the feed-in tariff adjustment mechanism that was implemented in June 2012 (as described in section 3.2.2). The model calculations of the feed-in tariff levels from January 2014 onwards use rooftop systems of up to 30 kW as representative category. As the feed-in tariff adjustment is formulated based on total deployment volume, the model assumes that the market share of projects of up to 30 kW from between 2010 and 2012 (30% yearly average) stays constant from 2014 onwards. Feed-in tariff rates for systems of up to 30 kW from April 2012 onwards are calculated as average rates between the tariff levels of the newly implemented size categories for systems of up to 10 kW and up to 40 kW respectively (see section 3.2.2). To simulate PV installations from January 2014 onwards, the model uses observed system price data until January 2014 from Photovoltaik-guide (2014), and assumes a further yearly continuous price decline by 14% (equal to average price decrease over the last 7 years).

In comparison to the basic model, the advanced model is able to simulate PV deployment with its characteristic demand peaks. Figure 3.8 shows that historic and model-based PV installations match fairly well.

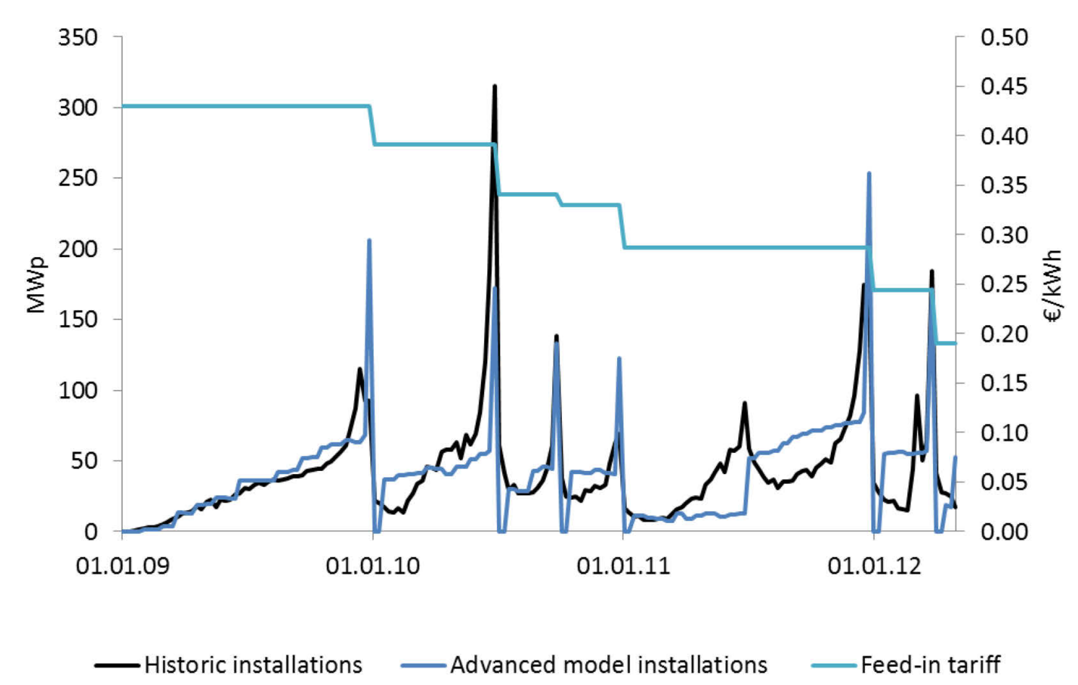


Figure 3.8. Historic and model-based weekly PV installations (advanced model) for systems of up to 30 kW

There was no feed-in tariff reduction on 1 July (and 1 September) 2011, as less than 875 MW of PV systems was registered at the Federal Network Agency between March and May 2011.

However, market demand peaked before July 2011, due to temporary uncertainty about potential tariff cuts. On 1 January 2012 the degression amounted to 15%, as 5.2 GW were registered between October 2010 and September 2011.

3.5.2 Model results for alternative design options

In 2011 and 2012, alternative options for the design of the PV feed-in tariff adjustment mechanisms were brought forward by different political parties. Several design options are assessed in this section with the quantitative model previously introduced. In particular, the focus of this analysis is on the impact of the following variables:

- degression frequency;
- adjustment flexibility; and
- qualifying period.

Table 3.1 defines five different design options with their respective parameters. These design choices contain monthly and quarterly degression frequencies, with adjustment rates being either fixed, or dependent on installations in previous months, and in the latter case with qualifying periods of either 3 or 12 months.

Table 3.1. PV feed-in tariff design options with parameters

Name	**Dm P3**	**Dm P12**	**Dq P3**	**Dq P12**	**Df**
Degression frequency	Monthly	Monthly	Quarterly	Quarterly	Quarterly
Basic degression	1%	1%	2.97%	2.97%	4%
Degression corridor	-1.5% (p.q.) – 2.8% (p.m.)	-1.5% (p.q.) – 2.8% (p.m.)	-1.5% - 8.17%	-1.5% - 8.17%	-
Qualifying period	3 months	12 months	3 months	12 months	-

The "Dm P3" and "Dm P12" designs contain a monthly 1% degression, which can vary between 0% (-1.5% each quarter) and 2.8% depending upon the amount of installations during the previous 3 and 12 months, respectively. Degression rates are calculated and implemented each month, compared to the current feed-in tariff design with quarterly determinations and monthly implementations. The "Dq P3" and "Dq P12" designs use a quarterly frequency with a basic 2.97% degression (which corresponds on a yearly basis to a monthly 1 % degression). As there is a time lag of one month between qualifying periods and corresponding degression dates in the adjustment design currently in place, the same is implemented in all four flexible design options in Table 4.1. The "Df" design includes a fixed quarterly 4% degression.

The feed-in tariff design mechanisms discussed in this paper do not take incentives for the replacement of older systems into account. The degradation of poly- and monocrystalline PV systems including modules is 0.1% relative decrease of the efficiency factor on average per year (Wirth, 2014). In this regard, legacy PV plants which were installed several years ago perform relatively similar to recently installed systems.

Figure 3.9 shows the evolution of model-based PV feed-in tariffs (for systems of up to 30 kW) for all feed-in tariff design options in the period January 2014 – December 2016.

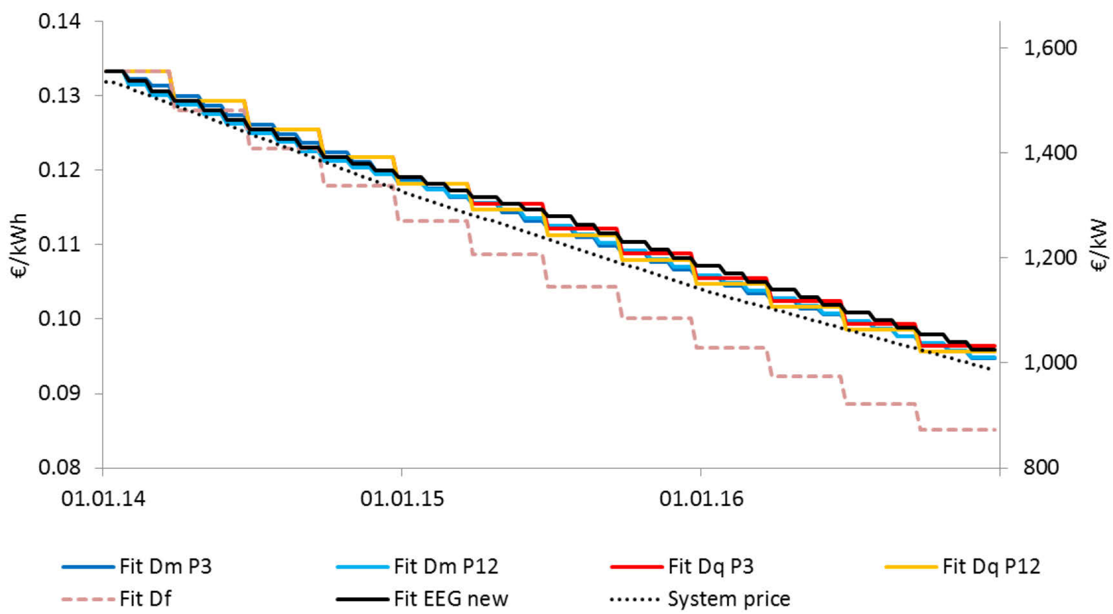


Figure 3.9. PV feed-in tariff rates for systems of up to 30 kW for different adjustment design options

While the "Dq P12" design option with quarterly degressions and a qualifying period of 12 months delivers constant 2.97% degression rates, all other responsive design options flexibly adjust degressions around their basic rates, given a continuous yearly 14% decline of system prices. The newly implemented feed-in tariff scheme ("EEG new") first delivers monthly 1% degressions, and then flexibly adjusts for 0.75% and 1% rates. The design with quarterly degressions and a qualifying period of 3 months leads to the highest tariff level (9.64 ct/kWh), while the fixed "Df" design reaches the lowest tariff rate (8.51 ct/kWh) at the end of 2016.

According to the newly amended Renewable Energy Sources Act (EEG) of June 2012, the future target corridor for supported PV installations amounts to 2.5 to 3.5 GW per year. Assuming that the 30% market share of small-scale systems of up to 30 kW (yearly average between 2010 and 2012) will stay constant from 2014 onwards, this corresponds to a quarterly target corridor of 188 to 263 MW for these installations. Figure 3.10 shows model-based installations for the different feed-in tariff adjustment designs on a quarterly basis for the simulated period 2014 until 2016, as well as the respective target corridor.

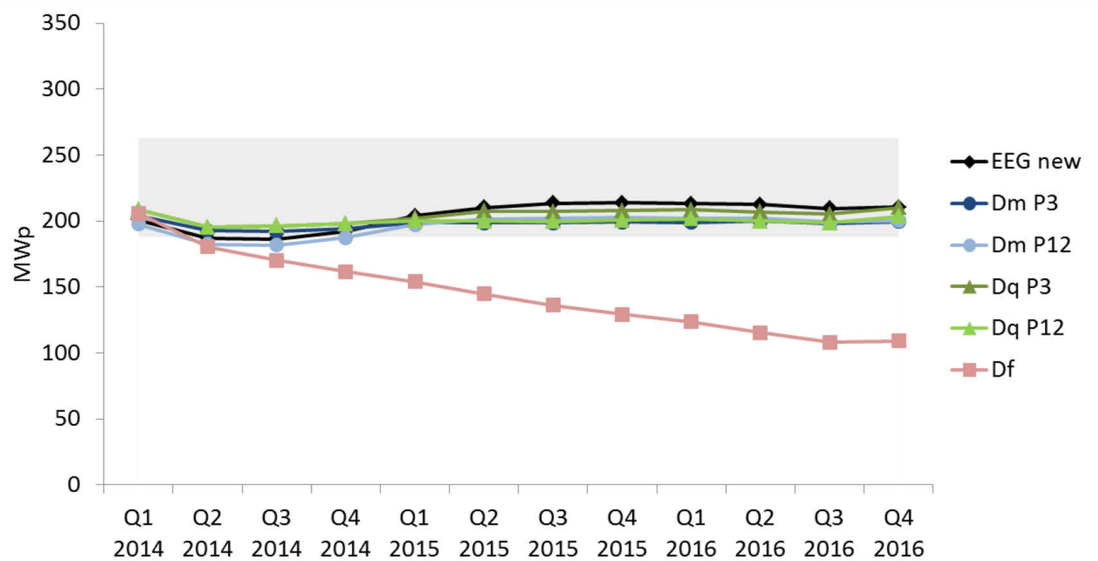


Figure 3.10. Quarterly PV installations up to 30 kW for different feed-in tariff designs and target corridor

Given the continuous price decline of 14 percent per year, model-based installations converge within their target corridor for all responsive feed-in tariff adjustment mechanisms. This shows that flexible feed-in tariff schemes are able to guide deployment along stated volume targets. The alternative design option with fixed degression rates results in decreasing installations falling far below the target corridor, as tariff levels decline faster than system prices.

However, the future price development is not known at the time of decisions on the adjustment mechanism. While policy changes can partially be anticipated during political negotiation processes in advance, the future price development of PV systems is difficult to predict. Therefore, the designs need to be tested against different potential price scenarios. The evolution of PV system prices from 2014 onwards is difficult to anticipate due to several reasons. First, because there are global production overcapacities for new PV modules. Second, because demand for PV modules depends on the evolution of feed-in tariffs and other policy schemes in many countries, and is difficult to forecast.

This analysis uses the following scenarios for the evolution of system prices for small-scale PV installations in Germany. Figure 3.11 shows the respective prices in all scenarios within the simulation period.

Reference scenario (S1): In this business-as-usual scenario, the price continuously declines from 2014 onwards at a yearly rate of 14 percent (average during last 7 years, as defined in section 5.1). To allow for a detailed assessment of convergence of the deployment volume to target levels after unexpected changes of PV system prices, the reference scenario ensures that the installation volume matches the target deployment (between 188 MW and 263 MW per quarter for systems of up to 30 kW).

Scenario 2 (S2): The price evolves as in the S1 scenario, with a one-off price increase of 10 percent on 1 July 2014. This is to analyze situations like the recent increase of module prices because of trade disputes between the European Union and China.

Scenario 3 (S3): The price develops as in the S2 scenario, with a price reduction of 20 percent on 1 January 2015.

Scenario 4 (S4): The price evolves as in the S1 scenario, with a price reduction of 15 percent on 1 July 2014.

Scenario 5 (S5): The price develops as in the S4 scenario, with another price reduction of 10% on 1 July 2015.

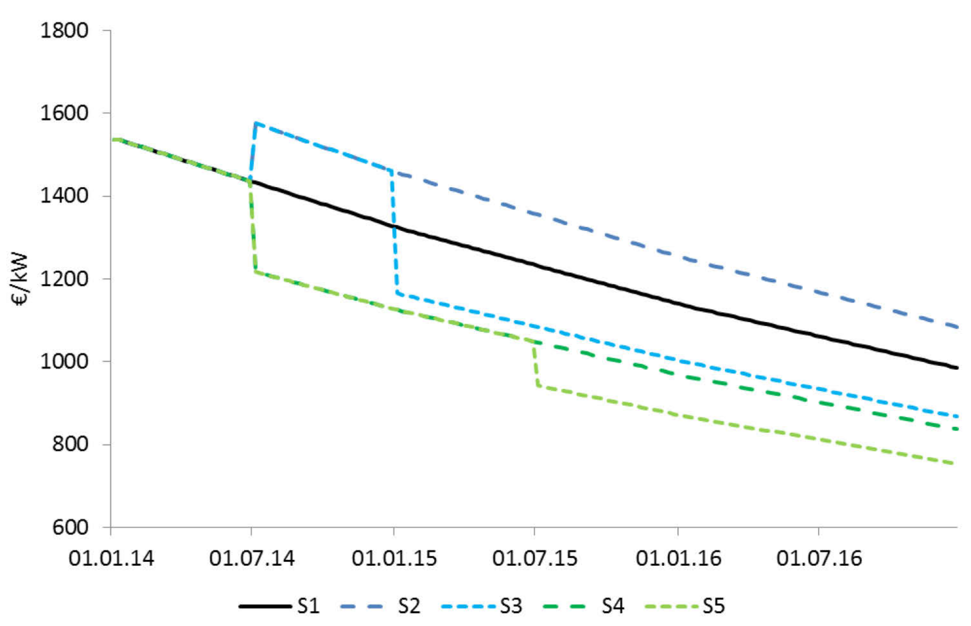


Figure 3.11. PV system prices for installations up to 30 kWp in model scenarios

While the “Df” feed-in tariff design includes fixed 4% reductions every three months, feed-in tariff cuts in the flexible adjustment designs depend on the amount of PV capacity installed in the previous months, and thereby differ in the respective system price scenarios. Table 3.2 summarizes model-based feed-in tariff rates for all adjustment designs in the different price scenarios.

Table 3.2. Feed-in tariff rates [ct/kWh] for systems of up to 30 kW at the end of 2014, 2015 and 2016 for different feed-in tariff designs and price scenarios

Scenario	Year	Feed-in tariff design				
		Dm P3	**Dm P12**	**Dq P3**	**Dq P12**	**Df**
S1	**2014**	12.00	11.95	12.18	12.18	11.80
	2015	10.66	10.70	10.88	10.80	10.02
	2016	9.47	9.48	9.64	9.57	8.51
S2	**2014**	12.21	11.98	12.18	12.18	11.80
	2015	11.35	11.22	11.47	11.30	10.02
	2016	10.14	10.28	10.24	10.40	8.51
S3	**2014**	12.21	11.98	12.18	12.18	11.80
	2015	10.67	10.86	10.90	11.04	10.02
	2016	9.16	9.17	9.32	9.33	8.51
S4	**2014**	11.90	11.89	12.18	12.18	11.80
	2015	10.05	10.20	10.29	10.42	10.02
	2016	8.80	8.72	9.02	8.80	8.51
S5	**2014**	11.90	11.89	12.18	12.18	11.80
	2015	10.05	10.20	10.29	10.42	10.02
	2016	8.45	8.61	8.59	8.80	8.51

While the “Df” design leads to the lowest feed-in tariff at the end of 2016 in most scenarios, the “Dm P3” design reaches the lowest level in the S5 scenario. With regard to the flexible design options, the “Dq P12” design results in higher tariff rates at the end of the simulation period than the design options with monthly degressions in all scenarios.

Table 3.3 shows average profit margins (per kW installed) during the simulation period for the different feed-in tariff designs and price scenarios. Certain shares of these margins are needed to cover project development costs and risks like for instance the failure of components during the lifetime of 20 years.

Table 3.3. Profits (average margins) [€/kW] for systems of up to 30 kW for different adjustment design options and price scenarios during simulation period

	Feed-in tariff design					
Scenario	**Dq P3**	**Dq P12**	**Df**	**Dm P3**	**Dm P12**	**EEG new**
S1	298	291	216	287	285	298
S2	261	255	168	258	247	249
S3	395	395	297	386	388	387
S4	403	408	361	392	397	402
S5	436	454	406	428	442	447

The fixed degression design leads to lowest profit values, as corresponding installations develop below simulated deployment of the flexible feed-in tariff designs and in some scenarios significantly below the target range (see also figures 3.10 and 3.12 to 3.15). With regard to the responsive design options, the "Dm P12" design with monthly degressions and a qualifying period of 12 months results in lowest profit margins in scenarios 1 and 2, while the "Dm P3" design results in lowest margins in the scenarios with excess deployment (see figures 3.13 to 3.15 for scenarios 3, 4, and 5). This illustrates that feed-in tariff mechanisms with monthly adjustment frequency lead to lower deployment and corresponding profit margins than degression schemes with quarterly frequency.

Mitchell et al. (2011, p. 883) define policy effectiveness as "the extent to which intended objectives are met, for instance the actual increase in the amount of RE electricity generated or share of RE in total energy supply within a specified time period". In the following, the focus is on the effectiveness of the different PV feed-in tariff design options as the extent to which the annual target corridor between 2.5 and 3.5 GW of installations is met.

The target corridor for systems of up to 30 kW, assuming that they continue to constitute 30% of the market (yearly average between 2010 and 2012), corresponds to a deployment volume between 750 and 1050 MW on a yearly basis, and between 188 to 263 MW on a quarterly basis respectively. Figures 3.12, 3.13, 3.14 and 3.15 show the respective deployment levels for the different price scenarios.

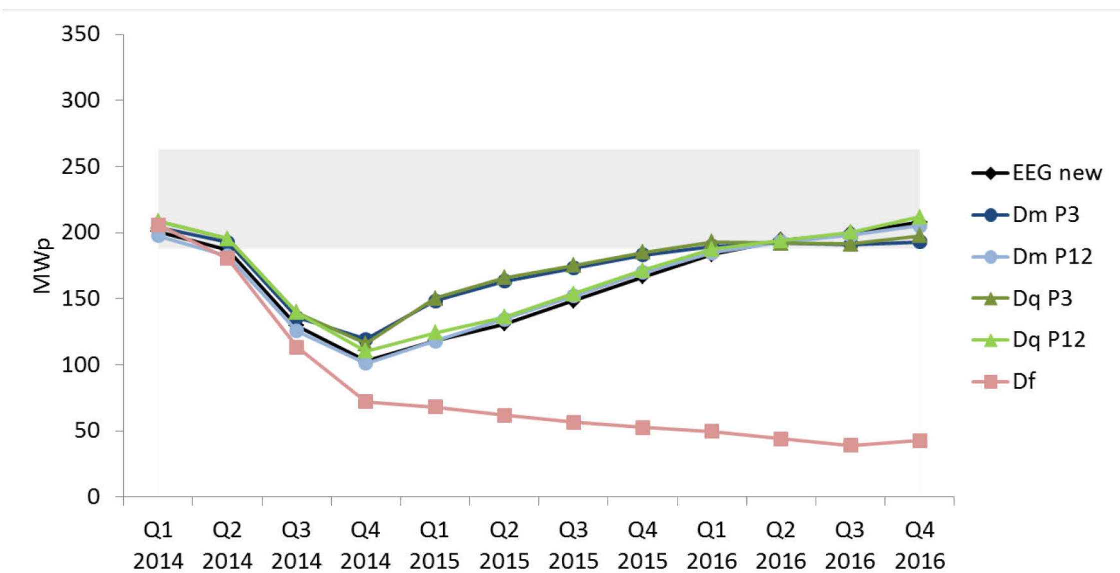


Figure 3.12. Quarterly PV installations for systems of up to 30 kW for different feed-in tariff designs between 2014 and 2016 in S2 scenario

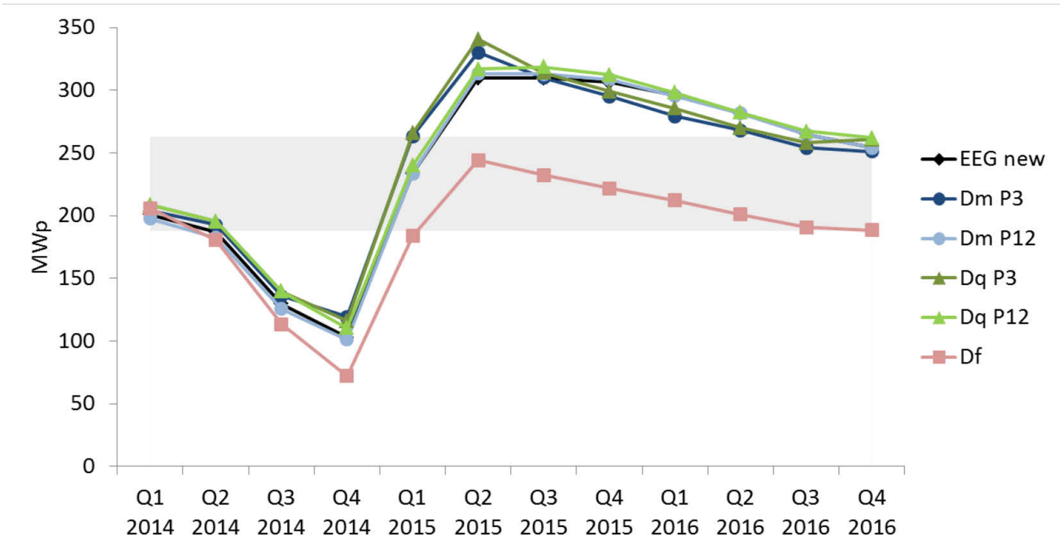


Figure 3.13. Quarterly PV installations for systems of up to 30 kW for different feed-in tariff designs between 2014 and 2016 in S3 scenario

The abrupt price increase in July 2014 in the S2 scenario leads to deployment falling strongly below the target corridor for all feed-in tariff design options. Accordingly, degression levels decrease within the flexible feed-in tariff adjustment schemes, so that from 2015 onwards all responsive mechanisms result in increasing quarterly installations again. Figure 3.12 shows that the degression schemes with qualifying periods of 3 months are the fastest in recovering deployment and converge within the target range from Q1 2016 onwards. In contrast, the adjustment design options with longer qualifying periods take longer to lead installations back to the target corridor. Following the sudden price decline at the beginning of 2015 in the S3 scenario the responsive degression levels increase, resulting in deployment exceeding the target corridor, as shown by Figure 3.13. Again, the design options with short qualifying periods are faster in leading installations back on track in 2016. Model results show that the impact of monthly or quarterly degression adjustments on quarterly installations is relatively similar.

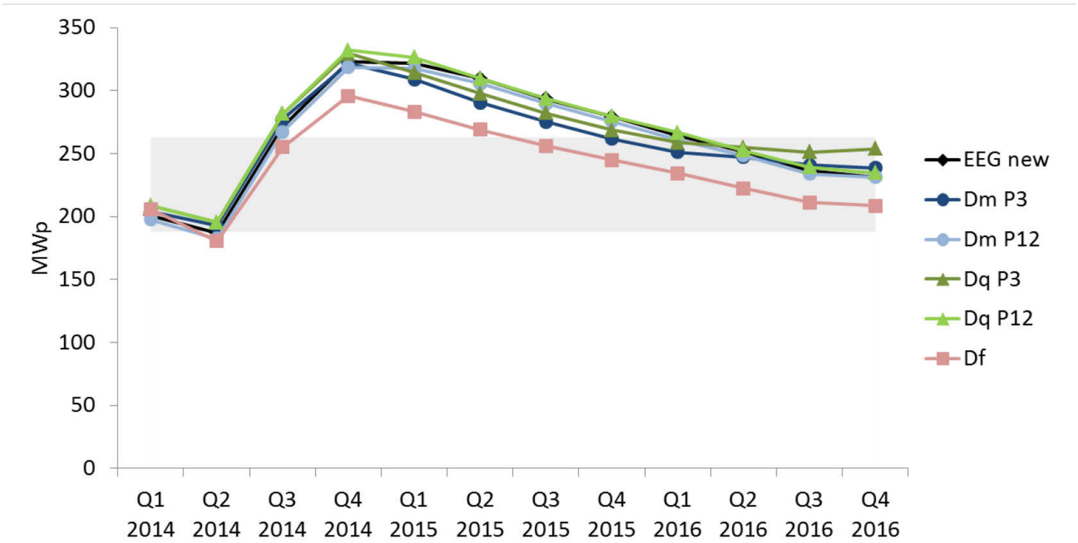


Figure 3.14. Quarterly PV installations for systems of up to 30 kW for different feed-in tariff designs between 2014 and 2016 in S4 scenario

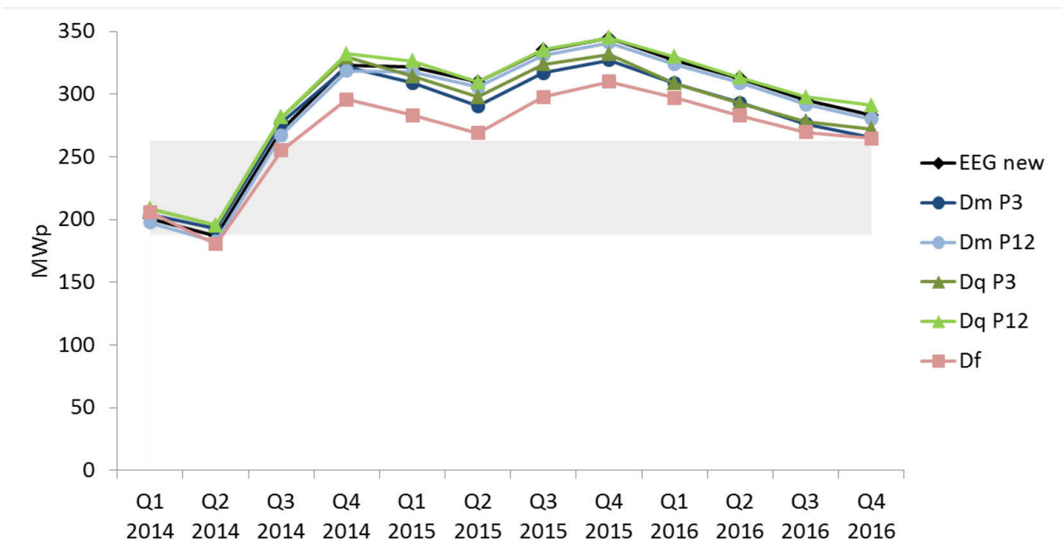


Figure 3.15. Quarterly PV installations for systems of up to 30 kW for different feed-in tariff designs between 2014 and 2016 in S5 scenario

While the S4 scenario contains a 15 percent price decrease in July 2014, the S5 scenario includes an additional 10 percent decline one year later. Similar to the other scenarios, feed-in tariff adjustment designs with short qualifying periods of 3 months are faster in correcting deviating deployment, as shown by figures 3.14 and 3.15. Because of their long qualifying periods, the other flexible schemes are relatively slow in responding to quickly changing PV system prices.

3.6 Conclusion

This paper reviews the experience with the adjustments of the feed-in tariff scheme for solar photovoltaics in Germany. The National Renewable Energy Action Plan of the German government targets the installation of 52 GW of PV power generation capacity in Germany by 2020. The amended Renewable Energy Sources Act (EEG) from June 2012 defines a yearly target corridor between 2.5 GW and 3.5 GW for new PV installations. However, in 2010, 2011 and 2012 yearly PV deployment was around 7.5 GW.

This shows that setting appropriate levels for feed-in tariffs is a challenge, especially as PV system prices decreased faster than expected since 2009. Thereafter, the feed-in tariff for new installations was adjusted by several short-term political interventions. Despite the differences between these individual adjustments, the market responded in a similar manner in all cases. In periods prior to feed-in tariff reductions the volume of installations always peaked as investors aimed to still qualify for the higher tariff levels. In this regard, larger projects are usually more responsive to changing support schemes. However, as small-scale PV installations of up to 30 kW account for a large share of total installations in Germany, and as they have relatively short planning and construction periods, this work focuses on the small-scale roof-top category of the German PV feed-in tariff. In comparison to large ground-mounted PV projects, private investors with small-scale residential systems are able to more closely time their investment decisions in response to price changes.

The analytic model developed in this paper is able to simulate the evolution of new PV installations and feed-in tariffs on the basis of observed PV system prices. This simple model is based on only three factors: (i) deployment increases proportionately with project profitability; (ii) profit expectations of investors decreased over time; and (iii) in periods preceding feed-in tariff reductions, projects are implemented faster to still qualify for the higher tariffs.

Model results show that demand responds very quickly (as project duration of small-scale PV systems is only seven weeks on average) to moving system prices and policy changes. Larger profitability leads to increasing installation numbers. The demand peaks result from accelerated projects that are completed in the week immediately prior to a feed-in tariff reduction. Overall, the simulated installation volumes closely match the observed weekly deployment numbers.

This suggests that the analytic framework has identified the main factors driving deployment choices. However, in the future or for other project sizes, investors might also respond to other factors changing deployment volumes, like uncertainty of policy development or a mobilizing effect if there are perceptions of a last opportunity to qualify for support. For the simulation of the coming years, the model assumes that the majority of investors will continue to realize projects because of prospective feed-in tariff support. However, in the case of further strong system price declines and following tariff reductions in the future, the share of projects without receiving feed-in tariffs might grow.

The analytic model allows for the analysis of feed-in tariff adjustment mechanisms with different degression frequencies, adjustment flexibilities, and qualifying periods. Thus, the model is used to simulate PV deployment and feed-in tariff levels for six policy design options in five PV system price scenarios. Model results show that responsive PV feed-in tariff adjustment mechanisms are suited to stabilize deployment and therefore avoid overfunding, provided that tariff adjustments are appropriately aligned with actual deployment. As forecasts for PV system prices are highly uncertain, a rigid degression scheme is fraught with risk. Responsive adjustment schemes with high degression frequencies can avoid strong pull-forward effects in periods preceding tariff reductions. Feed-in tariff designs with monthly adjustment frequency usually lead to lower deployment then degression schemes with quarterly frequency. Flexible feed-in tariff designs with short qualifying periods are the fastest in responding to quickly changing PV system prices.

3.7 Appendix

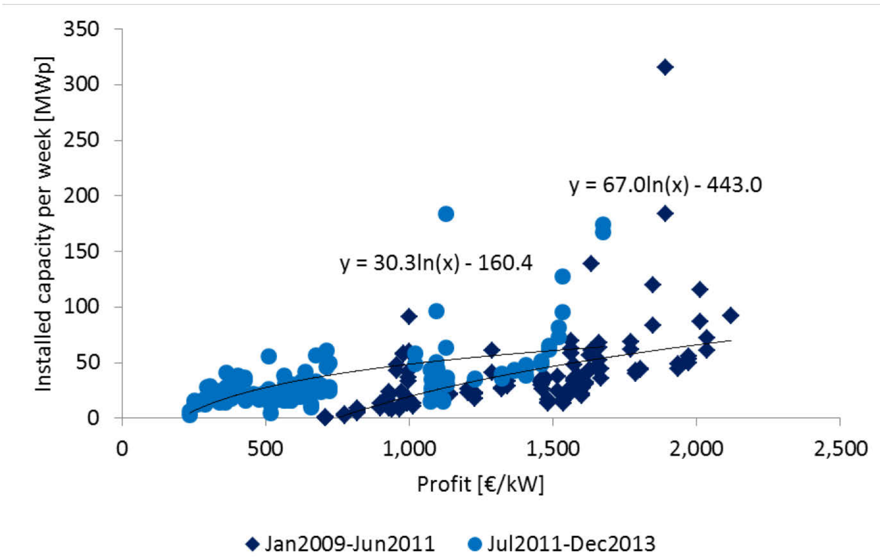


Figure 3.16. Weekly PV installations and profits for systems of up to 30 kW in Germany, logarithmic functional forms, 2009-2013

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4 Comparison of Feed-in Tariffs and Tenders to Remunerate Solar Power Generation

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Abstract

This paper analyzes the trade-offs for using feed-in tariffs or tenders to remunerate different scales of solar photovoltaics (PV) projects. In recent years, European countries increasingly combined feed-in tariffs for small renewables systems with tenders for large installations. This study develops an analytic framework to quantify deployment effectiveness of responsive feed-in tariff adjustment mechanisms across project scales and to compare specific cost effectiveness factors of feed-in tariffs and tenders for PV plants with their dynamic cost trends. To assess deployment effectiveness, an analytic model is used to simulate installations and feed-in tariffs for different project sizes. Then semi-structured interviews with German and French project developers are conducted to identify additional factors to be considered for a comparison of feed-in tariffs and tenders, and to explore how different remuneration schemes impact cost of capital and transaction costs. The paper finally discusses the relative merits of feed-in tariffs and tenders.

JEL Classification: O33, Q42, Q48.

Keywords: Feed-in tariff, tender, solar photovoltaics.

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4.1 Introduction

The academic literature usually differentiates two categories of policy instruments to support deployment of renewable electricity sources: price-based mechanisms, like feed-in tariffs or premiums, and quantity-based schemes, like tenders or quota systems (Menanteau et al., 2003, Butler and Neuhoff, 2008, Haas et al., 2011). Feed-in tariffs are the most common policy instrument to support renewable electricity globally, being implemented by 65 countries and 27 states / provinces, while tenders for renewables have been adopted by 33 countries in 2012 (REN21, 2012).

The combination of feed-in tariffs with tendering schemes has increased in European countries, from two countries having implemented this combination in 2005 to five countries in 2011, with more countries applying feed-in tariffs for small systems than for large installations across renewable electricity technologies, and most tendering schemes being applied for large-scale PV and biomass as well as offshore wind installations (Kitzing et al., 2012). For instance, based on its existing feed-in tariff scheme, France in 2011 included tenders for large-scale PV systems. The German Federal Ministry for Economic Affairs and Energy stated that the entire remuneration for ground-mounted PV installations shall be shifted from feed-in tariffs to tenders (BMWi, 2014). Despite the fact that several countries have introduced combined feed-in tariff and tender schemes, a thorough investigation of how to select an optimal threshold level has not been conducted so far. This leads to the research question for this paper: What are the trade-offs for using feed-in tariffs or tenders for the support of different scales of solar PV projects?

In a feed-in tariff system, investors receive a guaranteed price for renewable power generation (per kWh) for a specific time period. This remuneration price is determined administratively by public authorities. There are different general ways to structure the remuneration of feed-in tariffs (Couture and Gagnon, 2010). The German Renewable Energy Sources Act (EEG) with its fixed price feed-in tariff scheme has been effective in encouraging a rapid expansion of renewable electricity. However, despite several amendments and the introduction of flexible adjustment mechanisms, the feed-in tariff system led to strong overshoots of planned annual solar photovoltaics (PV) deployment between 2010 and 2012. This presents a challenge as the regularly increasing EEG levy leads to increasing electricity prices to consumers.

By contrast, tender mechanisms use an auction to determine the required remuneration levels. There are different types of tendering schemes used in the electricity sector to remunerate renewable power generation, with the remuneration price usually being the only or the most important evaluation criterion. The auction result can determine the premium or the full remuneration level. This work focuses on the experience with tenders in countries like France, Denmark, the UK, China, India, California and Brazil. In these tendering systems, investors bid a certain price for every kWh of electricity produced, which they need to install the plant. The final remuneration tariff is paid for a specific time period or a given amount of full load hours. The auction for wind farms in Brazil in 2009 resulted in an impressive 44% discount from the previous prices in the Proinfa (programme of incentives for alternative electricity sources) feed-in tariff program (Cunha et al., 2012). Moreover, tenders promise predictable deployment outcomes (as quantities are set) and control options regarding regional supply needs and network expansion. However, auction-based schemes imply several challenges and additional transaction costs relative to feed-in tariffs, like higher risks associated with project development (as not all bids will be successful), attrition because of speculative underbidding, or risks of market concentration. Batlle et al. (2012) recommend that regulators should move, as soon as there is sufficient competition between generators of renewable electricity, from feed-in tariffs to auctions.

This paper analyzes both deployment effectiveness of responsive feed-in tariff adjustment schemes and specific cost effectiveness factors of feed-in tariffs and tenders with a focus on different project sizes categories for solar PV plants with their dynamic cost trends. The hypothesis is that feed-in tariff remuneration is more effective and efficient for small PV installations, while tenders may be more suitable for large-scale projects.

PV projects are usually categorized into small residential rooftop systems, mid-scale commercial systems, as well as large ground-mounted plants. Reichmuth (2011) shows that private investors account for around 40% of new installations in Germany in 2009 and 2010, with average system sizes being concentrated between 5 and 10 kW, which is typical for one family houses. Farmers focus their investments on systems of around 30 kW (large rooftops, for instance on barns), while commercial and industrial investors account for a larger share of plants with 100 kW and more. According to Maron et al. (2011), the ownership structure in the PV sector in Germany is dominated by private persons who account for 39% of cumulative installations, followed by farmers (21%) and business (19%) in 2010. Project developers, funds and banks often invest in large ground-mounted PV plants.

This work assesses the distinctive characteristics of the different project size categories, including market evolution, project durations, administrative barriers, labor requirements, and financing risks. Using a unique dataset on weekly PV installations, this paper develops an analytic model to simulate weekly PV deployment and feed-in tariff levels for various project scales under the responsive tariff adjustment mechanism in Germany, accounting for differences in project profitability and duration (based on a linear regression analysis). 21 semi-structured expert interviews with international PV project development companies lead to additional insights about different cost effectiveness dimensions, in particular cost of capital and transaction costs. Most interview partners reported on their experiences with tenders in France, followed by South Africa. Therefore, this study compares financing and transaction costs for the German and French cases in detail.

The analysis shows that large installations, with their significantly longer project development times, are more responsive to changes in system prices and policy adjustments than small systems. Model results illustrate that the flexible German feed-in tariff scheme with its frequent tariff adjustments is able to reach deployment targets more effectively for small PV systems than for large-scale plants. Tenders lead to larger financing cost for project developers, relative to feed-in tariffs, in particular because of higher costs of equity and debt, with the weighted average cost of capital converging for large projects. Moreover, tenders imply longer project development times and higher project development cost.

The structure of the paper is as follows. The next section reviews the existing responsive feed-in tariff adjustment mechanism across project scales in Germany, and the remuneration system in France as one concrete case with feed-in tariffs for small systems and tenders for large installations. The third section develops the analytic framework, containing both the deployment model as well as the cost effectiveness dimensions. The fourth section describes the data for the deployment model, assesses the differences between small and large projects, and shows the simulation results. The fifth section describes the interview sample, and shows the interview results with regard to cost of capital and transaction costs. The final section offers conclusions.

4.2 Feed-in tariffs and tenders

This section reviews the evolution of the German PV feed-in tariff scheme with its responsive adjustment of remuneration levels across project scales, highlights challenges resulting from its current design, and introduces the governments' interest in implementing tenders for large installations. Thereafter, the paper assesses the French remuneration system as one concrete case with feed-in tariffs for small systems and tenders for large-scale plants, by describing its evolution and design, as well as the reasons for choosing the respective threshold levels.

4.2.1 Flexible feed-in tariff adjustment across project sizes: The German case

The German Renewable Energy Sources Act (*Erneuerbare-Energien-Gesetz*, EEG) with its fixed feed-in tariffs has been successful in deploying renewable energies in Germany: Their share in electricity generation increased from 6% in 2000, when the EEG was introduced, to 23.5% in 2012 (BMU, 2013). Solar PV feed-in tariffs in Germany are paid for 20 years, counting from commissioning, and are not indexed to the price level. While the German government defined annual targets for the deployment of renewable energies until 2020 within its National Renewable Energy Action Plan (BRD, 2010), the latest EEG amendment (EEG, 2012) defines an annual target corridor of between 2.5 GW and 3.5 GW for new PV installations.

Solar PV plants showed the strongest price reductions of all renewable energy technologies, as their system prices decreased by around 66% during the last six years (BSW-Solar, 2013). However, PV installations in most cases are not yet cost competitive with conventional power generation technologies, and therefore need further remuneration. After PV feed-in tariff levels were originally reduced by annual degression rates (like for other renewable energy technologies), several short-term degression adjustments were implemented between 2010 and 2012, due to the dynamic price evolution of PV modules. This shows the difficulty of ex-ante identifying the correct degression rate for a dynamic technology like PV.

The German government released the new version on the PV feed-in tariff adjustment mechanism in June 2012, with the law coming into force on 1 April 2012. This included a one-off tariff reduction on 1 April 2012, ranging between 20 to 29 percent for new installations. However, with regard to protection for reliance on existing law, several transitional provisions were implemented. For instance, ground-mounted installations further received the old feed-in tariff levels if the planning process had started before March 2012 and if the system was commissioned until 30 June 2012, while the commissioning time was extended until 30 September 2012 for installations on conversion areas.

Before April 2012, PV feed-in tariffs in Germany were categorized into 6 groups: rooftop systems up to 30 kW, to 100 kW, to 1000 kW, larger than 1 MW, as well as ground-mounted installations on conversion areas, and other spaces (remuneration for systems on agricultural fields was stopped in July 2010). Since April 2012, feed-in tariffs for rooftop systems are categorized according to new size categories: up to 10 kW, to 40 kW, to 1 MW, and to 10 MW, while ground-mounted PV systems up to 10 MW receive a uniform tariff level.

Since May 2012, PV feed-in tariffs are reduced on a monthly basis. To deliver the annual deployment corridor, degression levels depend on deployment since November 2012, are implemented on a monthly scale and adjusted every three months. To determine deployment and new feed-in tariff levels, the Federal Network Agency (*Bundesnetzagentur*) has a time period of one month. This implies a time lag between PV price reductions, corresponding deployment, and final feed-in tariff adjustment.

In recent years, the share of small-scale PV systems (≤30kW) decreased from 43% in 2009 to 23% in 2012, while the share of large-scale installations (>1MW) increased from 17% in 2009 to 42% in 2012. This shows that a balanced market growth of different project scales may be difficult to reach with the same feed-in tariff adjustment mechanism across size categories.

The German Federal Ministry for Economic Affairs and Energy aims at quickly and fundamentally reforming the EEG until summer 2014, and states that the entire remuneration for ground-mounted PV systems will be shifted to tendering mechanisms by auctioning 400 MW per year (BMWi, 2014).

4.2.2 Feed-in tariffs for small and tenders for large systems: The French case

In France, a feed-in tariff support scheme for PV systems was introduced in 2002 and amended several times in the years thereafter. Tariff levels for plants commissioned in 2009 ranged between 32.8 and 60.1 ct/kWh fixed for 20 years (Klein et al., 2010). In 2009, one call for tenders dedicated to overseas territories was introduced, but finally declared unsuccessful. After a boom of installations which applied for grid connection in 2009 and 2010, public authorities implemented a moratorium on feed-in tariffs, which lasted for three months.

The Charpin Trink concertation took place for three months during winter 2010/2011, gathering and interviewing all actors of the sector (Charpin and Trink, 2011). The call for tenders (*appel d'offres*) for PV installations larger than 100 kW (simplified tender) and larger than 250 kW was launched after the concertation in 2011, while a non-profitability feed-in tariff was published for plants larger than 100 kW. Another call for tenders was implemented in 2013. Thus, today there are feed-in tariffs for small systems up to 100 kW, and tenders for larger installations. One motivation to introduce tenders in France was to better control deployment volumes. Table 4.1 shows the current categories for the support of solar PV in France, based on MEDDE (2013), with the annual deployment target being 1000 MW.

Table 4.1. PV support categories in France

Installation type		Capacity	Support scheme	Annual target
Rooftop	Residential	0-9 kW	Feed-in tariff, revised quarterly	200 MW
	Non-residential	0-100 kW	Feed-in tariff, revised quarterly	200 MW
		100-250 kW	Simplified tender	120 MW
		>250 kW	Tender	At least 400 MW
Ground-mounted		>250 kW	Tender	

The reasons for choosing the thresholds of 100 kW and 250 kW for PV tenders are explained by the French Commission for Energy Regulation (Commission de régulation de l'énergie) as follows: (i) they are one of the conclusions of the Charpin Trink concertation, (ii) considering the electric network, the 250kW threshold is the limit between low voltage and medium voltage, and corresponds to a connection threshold for ERDF (Électricité Réseau Distribution France), the operator of the low and medium voltage distribution system, (iii) the feed-in tariffs described in the orders of January and August 2010 distinguished the threshold of 250kW, and (iv) the facilities between 100 and 250kW correspond to non-residential roofs, the category which had exploded during the 2010 bubble, so the new mechanism was designed to control its development.

The tenders are based on a points-based criteria system, with an overall maximum score of 30 points. Table 4.2 shows the weighting of the relevant criteria with their individual maximum scores for the respective tenders, based on CRE (2013a) and CRE (2013b). While the actual tariff level (price) receives most points in the simplified tender, environmental impact and R&D contribution are weighted stronger in the tender for plants larger than 250 kW.

Table 4.2. Criteria system with weightings (maximum scores) in French PV tenders

Criteria	Simplified tender (100 up to 250 kW)	Tender for installations larger than 250 kW	
		Sub categories 1a, 1b, 2	Sub categories 3, 4, 5
Price (tariff level)	20	12	12
Simplified carbon evaluation	10		
Environmental impact		10	8
Contribution to research and development		8	10
Total	30	30	30

The cumulative installed PV power generation capacity in France accounted for 4.03 GW at the end of 2012 (CGDD, 2013a). Installations larger than 250 kW have a market share of 44%, while systems between 100 and 250 kW represent a 21% share. New installations amounted to 1.7 GW in 2011 and 1.1 GW in 2012. 207 MW of new systems were installed in the first half of 2013 (73% less in comparison to the first half of 2012) (CGDD, 2013b), with 41% of these installations belonging to the size category between 36 and 100 kW.

4.3 Method, Analytic framework

The aim of the analytic framework developed in this section is to analyze the trade-offs for using feed-in tariffs or tenders to remunerate solar electricity generation. The underlying hypothesis is that the optimal policy scheme to support renewable energies depends on the size of investment projects. More specifically, the hypothesis is that feed-in tariff remuneration is more effective and efficient for small PV systems, while tenders could be more suitable for large-scale projects.

To investigate the research question, this study combines an analytic model based on quantitative regression analysis with qualitative case study research. The evaluation considers two policy objectives: Deployment effectiveness and cost effectiveness. The methodology used is novel in that it combines a linear regression analysis to analyze deployment effectiveness of responsive feed-in tariff mechanisms with semi-structured interviews to assess different aspects of cost effectiveness for remuneration through feed-in tariffs and tenders. The analysis was proceeded in two major steps.

First, 21 expert interviews were conducted with market professionals from international PV project developing companies based in Germany and France in 2013. An interview questionnaire (see Appendix) was developed building on insights generated through comprehensive literature review. This questionnaire served as the basis for a semi-structured discussion during the interviews. The questionnaire contains four parts: (i) characteristics and activities of the market experts and their companies, (ii) project development stages and process durations, (iii) project risks and probabilities of project abandonment, as well as (iv) project financing, cost of capital, and transaction costs. The interviews typically took between 20 and 60 min and were documented in interview transcripts.

Second, an analytic model was developed to quantitatively analyze deployment effectiveness (in terms of target achievement) of responsive feed-in tariff adjustment mechanisms with regard to different system size categories. This model was calibrated based on regressions of past deployment trends in Germany. The framework used by Grau (2012) for small-scale PV systems was expanded to allow for an assessment of different project sizes with their respective market characteristics, and modified with additional insights generated through the expert interviews.

4.3.1 Deployment model to analyze target achievement

Deployment effectiveness is measured in terms of reaching installations targets. A policy instrument works effectively if renewables deployment develops within a certain target corridor defined by the respective government, i.e. the optimal policy effectiveness shall correspond to supporting this deployment target corridor.

The model used to analyze deployment effectiveness for responsive feed-in tariff adjustment mechanisms is based on the factor that deployment and project profitability are positively correlated. Therefore, the methodological framework in this section is based on the basic model developed by Grau (2012). The approach considers a discrete-time economy. At the beginning of every period t, each investor (household, project developer, etc.) decides whether to invest in a PV project with a specific system size s, that would be finalized at date $t+d_s$, taking into account the average project duration d_s. PV installations $Y_{s,t+d}$ of system size category s at time $t+d$ depend on expected profitability $\pi_{s,t+d}$ according to the function

$$Y_{s,t+d} = \alpha * \pi_{s,t+d} - c, \quad (1)$$

with parameters of responsiveness α and c. Both parameters can be determined for different time periods, to account for changing profit expectations of investors over time.

Profits of PV projects are defined as net present value (NPV):

$$\pi_{s,t+d} = v_{s,t+d} - p_{s,t} \quad (2)$$

where $p_{s,t}$ is the average system price of size category s at date t and $v_{s,t+d}$ is the present value of the feed-in tariff of size category s at time $t+d$. Maintenance costs are relatively small and therefore neglected here.

The present value $v_{s,t}$ of the feed-in tariff is given by the equation:

$$v_{s,t+d} = f_{s,t+d} * h * \sum_{j=0}^{n} (1+i)^{-j}, \quad (3)$$

where $f_{s,t}$ is the feed-in tariff of size category s at date t, h is the amount of full load hours per annum, n is the amount of years which the feed-in tariff is paid for, and i is the annual interest rate.

In the framework of this model, the responsive interactions of deployment volumes and feed-in tariff adjustments (see section 4.2.1) are simulated for individual project size categories. This separate treatment of project scales allows to clearly identify their respective impacts on deployment effectiveness of responsive feed-in tariff adjustment mechanisms.

4.3.2 Expert interviews to analyze cost effectiveness

Cost effectiveness of public support for renewable electricity can be defined as minimization of renewable electricity generation costs, or as minimization of consumer costs (del Río and Cerdá, 2014). Cost effectiveness can also be called efficiency (Mitchell et al., 2011). This paper uses semi-structured expert interviews with international project development companies to explore how feed-in tariffs and tenders impact two specific dimensions of cost effectiveness: cost of capital and transaction costs. Section 4.5.1 describes the interview sample and the relevant countries. The following sub-sections explain the methodological framework to analyze cost of capital as well as transaction costs.

a) Cost of capital

The cost of capital contains the cost of equity and the cost of debt. To calculate the cost of capital, the WACC (weighted average cost of capital) approach is used here.

$$WACC = \frac{equity}{capital} * cost\ of\ equity + \frac{debt}{capital} * cost\ of\ debt * (1 - corporate\ tax\ rate) \qquad (4)$$

The cost of equity is defined as the risk-weighted projected return which is required by the investor. The cost of debt consists of the interest rate paid by the investor. Both cost of equity and cost of debt can be modeled as a risk free rate plus a risk premium. Corporate tax levels differ across countries.

Project financing is a common mechanism for companies to finance renewable energy projects, in particular for small project developers. Large firms can also use their ability to finance projects on their balance sheet (corporate finance).

Jager de and Rathmann (2008) define six levels of risk which can affect the cost of capital for renewable energy projects: project level risk (especially during construction and operation), regulatory risk (due to changes of policies), financial and market risk (like changes in interbank offered interest rates), legal risk, (geo)political risk (sovereign risk), and force majeure risk (e.g. concerning natural catastrophes). As this paper compares feed-in tariffs and tendering schemes, and in particular policies implemented in Germany and France, the focus is on the first three risk levels, while the other levels are assumed to be similar in both neighboring countries.

Both equity investors and lenders like banks assess the associated project risks and establish corresponding financial requirements like for instance the share of equity required. By focusing on PV project developers investing in countries with feed-in tariffs, Lüthi and Wüstenhagen (2012) empirically measure the price premiums which can be attached to policy risks like administrative process duration, policy stability, or the existence of a capacity cap.

Project developers (equity investors) use different metrics to determine the desirability of potential PV projects. A common metric of project profitability is the internal rate of return (IRR), or the internal rate of return after debt is serviced.

The internal rate of return r of an investment project is the discount rate that makes the net present value (NPV) equal to zero. Thereby, the investment I is contrasted with the sum of all discounted cash flows C_t at times t (with T periods).

$$NPV = \sum_{t=1}^{T} \frac{C_t}{(1+i)^t} - I = 0 \quad (5)$$

If the IRR is larger than the respective threshold, the investment will be attractive for the investor. The higher the IRR, the more desirable is the development of the project from an investor perspective.

The expert interviews in this regard focused on debt-equity ratios, cost of equity and cost of debt for different size categories, to allow for the calculation of WACC values across project scales for different countries. Finally, to enable a direct comparison of the cost of capital under feed-in tariffs and tenders, national WACC values are corrected for the yields of the respective ten year government bonds.

b) Transaction costs

In comparison to feed-in tariffs, tenders imply several transaction costs. Transaction costs for tendering schemes are diverse in nature. Based on the literature review, the most important transaction costs of tenders are costs for collaterals (deposits) for project developers (to avoid non-delivery), costs due to longer project development times because of the process duration of tenders, and costs incurred by bidders that subsequently fail to win in the tender.

To quantitatively analyze transaction costs, this study focuses on the additional project development time and costs necessary to participate in tenders in comparison to a feed-in tariff scheme, from the perspective of a representative investor, as they can be quantified by expert interviews. In particular, the analysis focuses on: (i) project development times, (ii) project development costs (including costs for collaterals in tenders), and (iii) costs due to the lower success rate in tenders.

To allow for a meaningful comparison of transaction costs under feed-in tariffs and tenders, the focus of this analysis is on the project development phase. This is often the most risky period of the project. From the construction phase onwards, factors like investment cost and remuneration rates could be equal under feed-in tariff and tender schemes. In tenders modules and equipment are usually only ordered as soon as the tender is won. To analyze cost for collaterals, the focus is on the point in time when the collateral is posted in the project development phase, and on the duration for which it is deposited.

4.4 Quantitative evaluation of deployment effectiveness

4.4.1 Data and parameter choices for deployment model

The regression analysis to assess the deployment effectiveness of the PV feed-in tariff adjustment mechanism in Germany is based on various data sources. This section describes the data used to calibrate the individual variables of the deployment model (see section 4.3.1). Moreover, the following paragraphs assess differences in market behavior of the individual project size categories, including the impact of profitability on deployment volumes and the responsiveness of investors to changes in sudden policy amendments.

Deployment, feed-in tariff adjustments, and market responsiveness

A period t corresponds to one week for the purpose of this application, as PV project durations range between 5 to 53 weeks in Germany (PVGrid, 2014). Feed-in tariff levels f and corresponding degression rates for the different installation types and system sizes between January 2009 and October 2013 are based on the respective versions of the Renewable Energy Sources Act (EEG) and (BNetzA, 2013).

Installations Y were aggregated for different system size categories during the time period between January 2009 and July 2013 based on system-specific data from the German Federal Network Agency for Electricity, Gas, Telecommunications, Post and Railway (*Bundesnetzagentur*) (BNetzA, 2013). Since January 2009, new PV installations must be registered at this agency. The Agency regularly publishes system-specific data for all installations, with date of registration, plant capacity, and locational information. Although this data does not provide information about installation types (like, for instance, residential rooftop, or ground-mounted on conversion areas), a careful assessment of policy evolution and market investment behavior in 2012 allows to derive the respective information.

Figure 4.1 shows weekly installations and exemplary feed-in tariff levels in 2012 for small systems up to 100 kW and large-scale installations. We observe a characteristic market behavior of investors: The deployment volume always strongly increased in periods prior to feed-in tariff reductions.

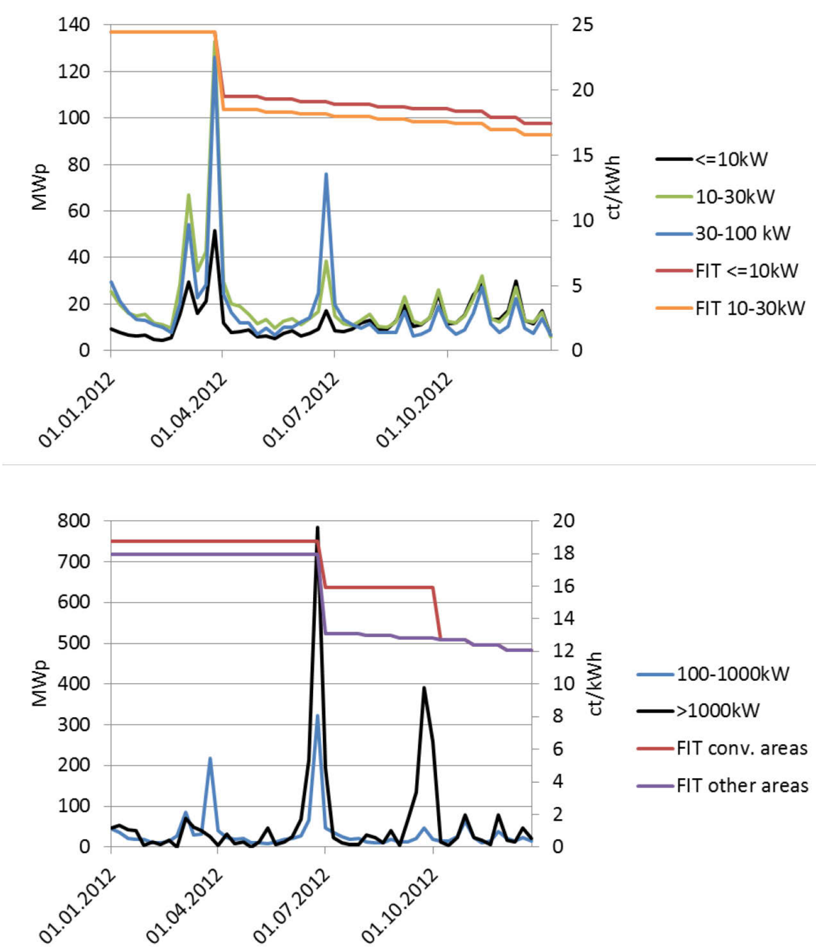


Figure 4.1. Weekly PV installations and exemplary feed-in tariff levels for different size categories in Germany in 2012

Investor behavior was clearly responsive to the various transitional provisions implemented by the government (see section 4.2.1). First, we observe strong demand peaks for small-scale systems in March 2012, prior to the respective one-off tariff reductions in April. These one-off tariff cuts were announced before the government released the new version on the feed-in tariff adjustment mechanism at the end of June. Small-scale installations slightly peaked again in June, prior to this release. Second, the strong demand peaks of large installations above 1 MW at the end of June and September 2012 respectively indicate that this size category mainly contains ground-mounted installations.

This market development illustrates that the monthly feed-in tariff adjustment frequency is actually implemented since April 2012 for small installations, and since July 2012 for ground-mounted plants. Figure 4.2 shows weekly deployment for small rooftop and large ground-mounted systems since October 2012.

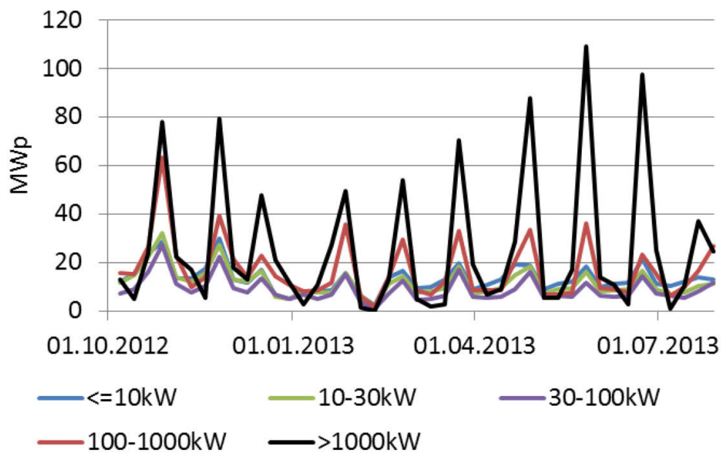


Figure 4.2. Weekly PV installations for small and large installations in Germany between October 2012 and July 2013

While demand peaks appear for all system size categories prior to the monthly feed-in tariff adjustments, these peaks are particularly strong for larger installations. This illustrates that large-scale installations are more responsive to changing support schemes.

The same market behavior can be observed when analyzing the previous time period between January 2009 and September 2012. Table 4.3 shows deployment peak intensity defined as the deployment within the last two weeks prior to a feed-in tariff reduction compared to the deployment in the weeks before with constant feed-in tariffs.

Table 4.3. Deployment peak intensity

	<=10kW	10-30kW	30-100kW	100-1000k	>1000kW
2009 W51-52	2.4	3.5	6.5	11.9	9.1
2010 W25-26	4.6	6.0	8.6	12.6	14.8
2010 W38-39	3.0	2.8	2.8	2.5	1.6
2010 W51-52	1.7	2.4	4.0	5.7	5.4
2011 W51-52	3.3	4.8	7.8	13.2	14.8
2012 W12-13	3.6	3.8	3.9	4.3	
2012 W25-26					18.8
2012 W39-40					7.2

This illustrates the extent to which deployment is responsive to extraordinary changes in profitability through abrupt policy changes. We observe that deployment peak intensity usually increases (from small values marked in green to high values marked in red) with project scale. While small-scale deployment (<= 10 kW) peaks by a factor of 3.1 on average, large-scale deployment peaks more than threefold stronger.

Figure 4.3 shows the relationship between deployment peak intensity and feed-in tariff reductions for small systems (<= 10 kW) and large-scale installations (> 1 MW) between 2009 and September 2012.

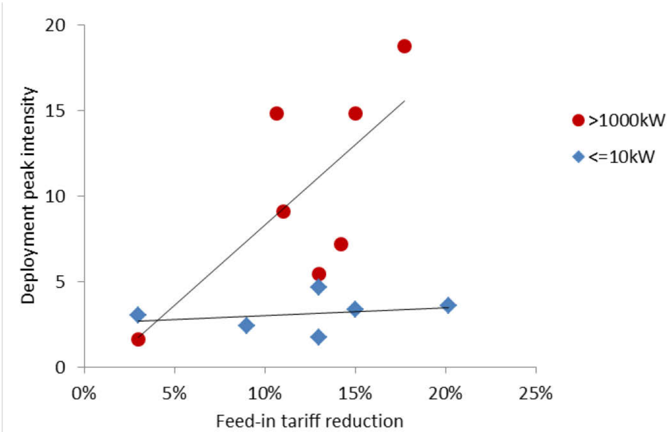


Figure 4.3. Deployment peak intensity and feed-in tariff reductions for small and large-scale systems between January 2009 and September 2012

While deployment peak intensity is relatively constant across feed-in tariff adjustments for small systems, peak intensity increases with the magnitude of feed-in tariff reduction for large-scale installations. This shows a combination of two factors: Project development companies with large-scale industrial plants have more flexibility to adjust project execution to meet certain commissioning dates, and they respond more strongly to price signals than private investors with residential rooftop systems.

Remuneration, system prices, and project durations

Feed-in tariff remuneration is paid for a time period n of 20 years. PV plants reach around 900 full load hours h per year in Germany. Yearly interest rates i are based on data published by (Bundesbank, 2013) for each month between January 2009 and August 2013.

Small-scale residential PV systems account for the largest specific investment costs per kWp, as they need the highest relative effort for project development and installation. Large-scale ground-mounted PV plants exhibit much lower system prices due to quantity discounts and standardization effects. The monthly system prices data between January 2009 and August 2013 for PV systems up to 100 kWp (after tax) from Photovoltaik-guide (2013) is therefore adjusted for different system sizes with fixed shift factors. Based on system size specific price data from IEA (2011) and Reichmuth (2011), small-scale systems up to 10 kWp are calculated to be 18% more expensive (than systems of 100 kWp), while installations larger than 1 MWp are 25% cheaper than systems up to 100 kWp.

The PV GRID database (PVGrid, 2014) provides detailed information on process duration, waiting time, labor requirements, and legal-administrative cost shares for all PV project development stages in different European countries. According to the database, project durations are relatively short for small-scale (3 kWp) residential PV systems (7 weeks on average) and mid-scale (50 kWp) commercial projects (9 weeks) in Germany. However, large-scale (2.5 MWp) industrial ground-mounted projects have significantly higher project durations, with 40 weeks on average. Moreover, while project duration ranges for small PV systems (between 5 and 10 weeks) and commercial installations (between 5 and 15 weeks) are relatively similar, these durations range between 24 to 53 weeks for large plants.

For the purpose of this deployment model, project durations *d* correspond to the respective average durations. Figure 4.4 shows weekly installations and profits (net present values calculated based on equations 2 and 3) for small and large projects for the time period 2009 until 2011.

Projects <=10 kW **Projects > 1 MW**

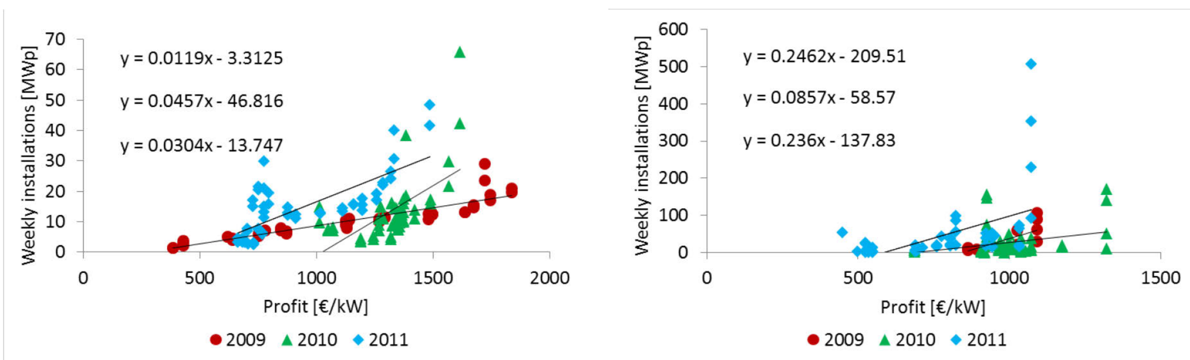
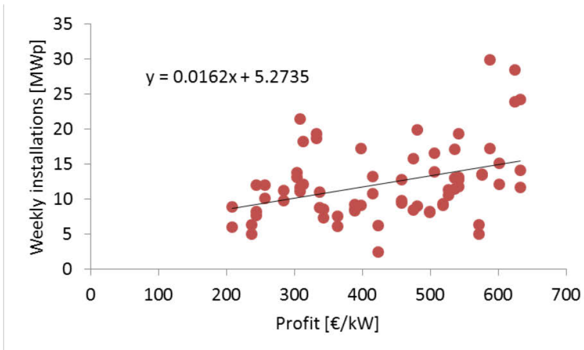


Figure 4.4. Weekly installations and profits for small and large systems in Germany between 2009 and 2011

Deployment positively correlates with project profitability for both small residential and large industrial PV projects. Large installations are more responsive to changes in profitability, as indicated by the higher slopes of the respective linear trendlines. Moreover, as mentioned before, we observe stronger peaks of large installations. This can be due to their longer project durations and larger duration ranges, which enable project developers to accelerate large projects to a higher extent than small projects prior to feed-in tariff adjustments.

To adequately represent the new feed-in tariff mechanism with its high adjustment frequency, the deployment model is based on data since the implementation of the monthly feed-in tariff adjustments. Figure 4.5 shows weekly installations and profits (net present values calculated based on equations 2 and 3) for small rooftop systems (<= 10 kW) and large-scale plants (> 1 MW) from April and July 2012 respectively until July 2013.

Projects <= 10 kW



Projects > 1 MW

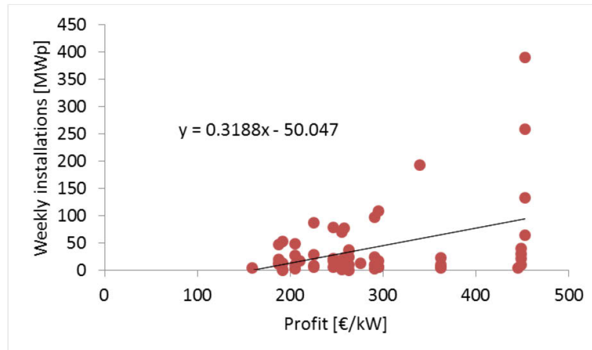


Figure 4.5. Weekly PV installations and profits in Germany since the implementation of monthly feed-in tariff adjustments (April and July 2012 respectively until July 2013)

A similar market behavior can be observed after the implementation of monthly feed-in tariff adjustments. Deployment positively correlates with project profitability for both small and large projects, with the regression coefficients being significant (p value of 0.001). The figure illustrates that again large installations are more responsive to changes in profitability levels.

4.4.2 Deployment model simulation and results

This section uses the analytic deployment model (see section 4.3.1) to simulate weekly PV installations and responsive feed-in tariff levels for different project scales under the current feed-in tariff adjustment mechanism in Germany. The simulation period is three years from August 2013 until July 2016 for weekly deployment, and between November 2013 and July 2016 for responsive feed-in tariff levels.

The simulation takes into account small residential systems (<= 10 kW) and large industrial plants (> 1 MW). The model could also be used to analyze deployment effectiveness of various mid-size project scales. The market share of the selected categories between 2009 and 2012 was 10 percent (<= 10 kW) and 29 percent (> 1 MW) respectively. With regard to the overall annual deployment target corridor of between 2.5 and 3.5 GW, these shares would correspond to separate weekly installation target corridors of between 4.8 and 6.7 MW for small systems (<= 10 kW), as well as between 13.8 and 19.3 MW for large plants (> 1 MW) respectively. As mentioned before, one policy objective is that PV deployment develops within a given target corridor.

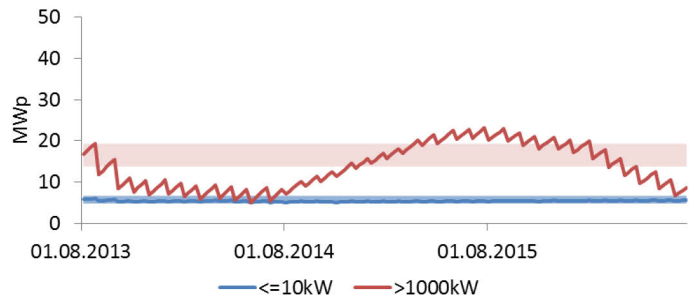
To ensure that deployment of each size category starts within the respective target corridor at the beginning of the simulation period, starting prices are calibrated: Taking into account the respective project durations (see section 4.4.1), the price for small systems (<= 10 kW) is set at 2041 €/kW in the week of 16 June 2013, while the price for large plants (> 1 MW) is set at 1222 €/kW in the week of 28 October 2012. To calculate new feed-in tariff degression rates in

November 2013 and February 2014, the model assumes that deployment levels within the respective qualifying periods correspond to the 3 GW yearly target corridor. From May 2014 onwards, degression rates are calculated depending on deployment in the respective previous 12 months, as defined by the law.

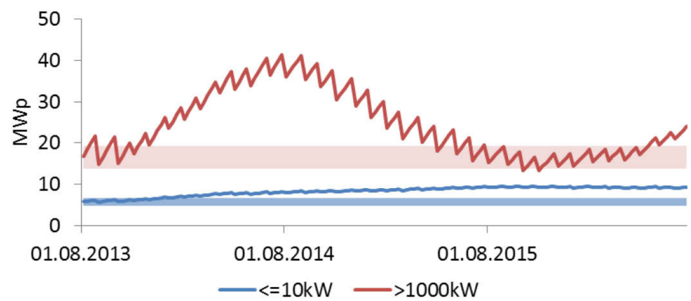
Due to the dynamic evolution of historic PV system prices, their future development is difficult to predict. Therefore, three possible price scenarios are used to simulate the achievement of deployment targets for different project scales. If deployment evolves within its target corridor, the current feed-in tariff adjustment mechanism in Germany sets basic degression rates at one percent per month, which correspond to an annual degression of 11.4 percent. In the first scenario, PV system prices therefore continuously decrease by corresponding 12 percent on a yearly basis. In the second scenario, prices decrease by 22 percent per year, according to the yearly average price reduction between January 2009 and January 2013. As module prices recently increased due to trade disputes between the European Union and China, the third scenario uses a yearly system price reduction of only 9 percent per annum.

Figure 4.6 shows model results for weekly PV deployment of different project scales within the German feed-in tariff adjustment mechanism under the three system price scenarios.

Scenario 1 with 12 percent yearly price decrease



Scenario 2 with 22 percent yearly price decrease



Scenario 3 with 9 percent yearly price decrease

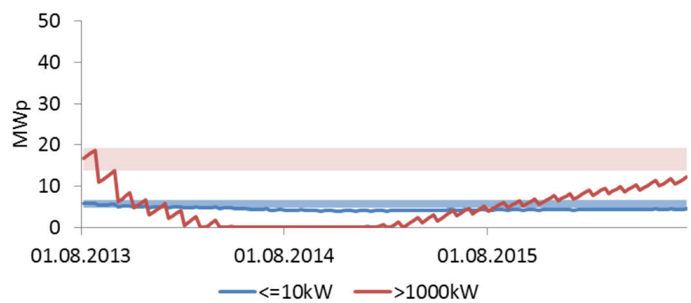


Figure 4.6. Model-based simulated weekly PV installations and target corridors for small and large projects with responsive feed-in tariff adjustment under different price scenarios

Weekly PV deployment of small systems develops within the respective target corridor in price scenario 1, as system prices decrease according to basic feed-in tariff degression rates. Due to their stronger responsiveness to changes in profitability, simulated deployment of large installations develops more volatile. After large installations initially fall below the target corridor in scenario 1, the responsive feed-in tariff mechanism leads them back on track in November 2014.

If module and installation prices develop very differently from the envisaged trajectory, installation volumes will strongly deviate from their target corridors. This is due to the design of the current responsive feed-in tariff scheme in Germany: There is no real-time adjustment of feed-in tariffs to system price levels, but tariffs are adjusted depending on installations in the respective previous 12 months. Furthermore, the Federal Network Agency only publishes actual deployment and corresponding degression levels with one month lag. Therefore, this mechanism leads to a time lag between changes in system prices and feed-in tariff adjustments.

If system prices decrease by larger rates, as shown in scenario 2, profitability margins increase, causing excess deployment. This leads to increasing feed-in tariff degression rates, but because of the time lag mentioned before installations further increase until July 2014 for large plants (41.5 MW maximum weekly deployment, corresponding to 252% target achievement relating to corridor center), and until December 2015 for small projects (9.5 MW maximum weekly deployment, corresponding to 167% target achievement relating to corridor center). Responsive monthly feed-in tariff degression rates therefore reach a maximum level of 2.2% for large installations between November 2014 and July 2015, and of 1.8% for small systems between November 2015 and July 2016 respectively. The advanced deployment model developed by Grau (2012) can be used to show that flexible feed-in tariff adjustment mechanisms with shorter qualifying periods (3 months instead of 12 months) are faster in correcting excess deployment for small-scale installations.

Scenario 3 shows a similar development: weak price reductions lead to smaller profitability margins, resulting in deployment below target corridors. The relatively low profit margins of large-scale projects even prevent any deployment between May 2014 and December 2014. However, the responsive feed-in tariff adjustment scheme is able to correct this trend from the beginning of 2015 onwards.

The major difference in deployment deviating from target corridors across project scales lies in the respective orders of magnitude. As large-scale PV projects are more responsive to changes in profitability levels (see section 4.4.1), the model simulations clearly illustrate that resulting target deviations are much stronger for large plants than for small systems.

Table 4.4 shows model results for PV deployment in Germany (yearly averages), target corridors, and target achievement (relating to center of target corridor) for small and large PV plants under different price scenarios.

Table 4.4. Yearly target corridors, simulated annual deployment, and target achievement

	Target corridor [MWp]			Simulated deployment [MWp]			Target achievement [%]		
	from	to	mid	Sc. 1	Sc. 2	Sc. 3	Sc. 1	Sc. 2	Sc. 3
<=10kW	247	346	296	277	429	230	93%	145%	78%
>1000kW	715	1001	858	716	1259	237	83%	147%	28%

For the responsive feed-in tariff mechanism in Germany, simulated deployment develops on average within the respective target corridors in scenario 1. Table 4.4 illustrates that target deviations are stronger for large-scale plants than for small systems. If deviations below and above the target corridor were considered to be equally relevant in terms of deployment effectiveness, target deviations in the scenarios evaluated are 50 MWp for small projects and 368 MWp for large installations on average in absolute terms (relating to corridor boundaries). Target achievement in relative terms (relating to corridor centers) is similar for small and large projects in scenario 2, but differs strongly in scenario 3.

The model results show that responsive feed-in tariff schemes with frequent tariff adjustments are able to reach deployment targets relatively effectively for small-scale PV systems. However, for large installations, the target corridor is more difficult to reach with flexible feed-in tariff adjustment mechanisms.

Tender schemes with set quantities for large-scale installations could improve overall achievement of deployment targets. However, there are large differences in actual implementation rates of approved projects in countries with tenders. In the UK, the Non-Fossil Fuel Obligation (NFFO) tendering scheme resulted in contracts for 3270 MW of wind power declared net capacity (DNC) between 1990 and 1998, but only 29% of these projects were realized by September 2003 (Butler and Neuhoff, 2008). In California, a typical assumption is that 40% of projects contracted through tenders will be commissioned (expert interview).

4.5 Results on cost effectiveness factors

This section describes the interview sample, and subsequently presents and analyzes interview results on specific factors impacting cost effectiveness, in particular cost of capital and transaction costs, of feed-in tariffs and tenders in selected countries.

4.5.1 Interview sample

The results in this study are based on interviews with 21 experts from 19 German and French PV project development companies. These companies include large vertically integrated firms who develop, construct and operate projects, as well as small specialized firms. Around 60 percent of these firms have more than 100 employees. The experts interviewed include several chief executive officers, as well as directors and project managers. The interviews were conducted between May and October 2013, by phone and at a solar industry fair.

The project developers interviewed are engaged in PV projects around the world, and have most experience with project development under a tendering scheme in France (12 companies), followed by South Africa (10 companies). Other countries mentioned include India, Turkey, the US, Australia, Portugal, Cyprus, Indonesia, Bangladesh, Ghana, Botswana, Mexico, and Chile.

The following sections will therefore mainly focus on a comparison of the German feed-in tariff system with the tendering schemes in France, and partially South Africa, due to the large amount of interview results obtained for these countries.

4.5.2 Cost of capital

Before developing a PV project, investors and lenders assess the risks involved in the remuneration mechanism and the country in focus. The higher the risks involved, the larger are required returns on equity and debt interest rates. Project financing costs increase with higher equity shares, cost of equity and loan interest rate. This section focuses on the effects of feed-in tariffs and tenders on the weighted average cost of capital, by comparing equity shares as well as cost of equity and debt across policy schemes.

The results from the semi-structured expert interviews are grouped into 5 categories within this section: a residential rooftop system (5 kWp), two commercial rooftop systems (50 and 200 kWp), and two ground-mounted systems (1 and 5 MWp). The majority of project developers interviewed focus their business on large installations.

Figure 4.7 shows equity shares in project financing reported by project developers for different project scales (in kWp) in Germany, with minimum, average, and maximum values.

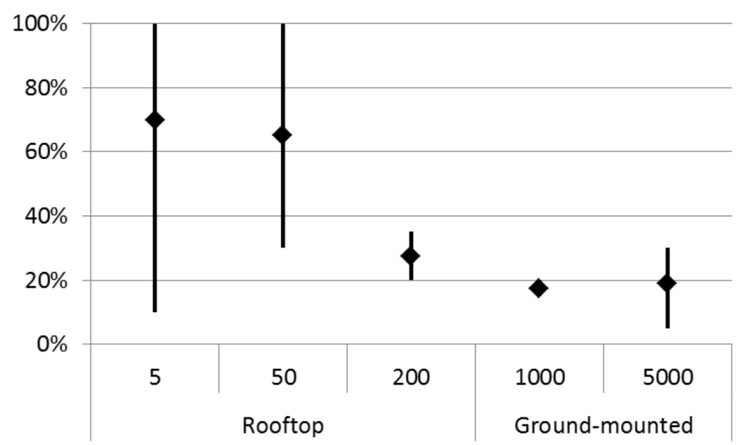


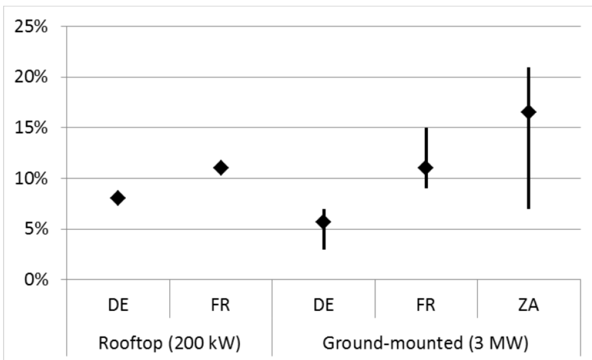
Figure 4.7. Equity shares across project scales in Germany

Interview results show that equity shares in project financing tend to decrease with increasing system size. Private investors usually finance their small residential PV systems with high equity shares, and in recent years often by equity only. Companies investing in large-scale projects use higher shares of debt financing. Due to the leverage effect, use of low interest debt leads to lower overall support costs. While a 20% equity share for investing in ground-mounted plants is common, the share is slightly higher for large rooftop systems.

To finance projects in countries with tendering schemes, project developers use similar shares of equity, with values on average being 30% for large rooftop systems (200 kWp) and 20% for ground-mounted installations (1 and 5 MWp) in France, and 23% for ground-mounted plants in South Africa. Therefore, the differences between feed-in tariff remuneration and tendering schemes seem to have an insignificant impact on equity shares in project financing.

Figure 4.8 shows cost of equity and cost of debt for investing in different project scales in Germany, France and South Africa, with minimum, average, and maximum values.

Cost of equity



Cost of debt

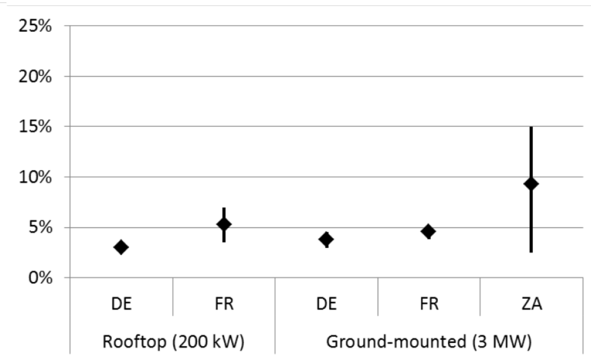


Figure 4.8. Cost of equity and cost of debt across project scales in Germany, France and South Africa

The cost of equity (required rate of return on equity) is generally higher than the cost of debt (debt interest rate). Equity providers get compensated with larger returns, as they face higher risks in project financing than lenders.

Project developers reported that the cost of equity is higher under tendering schemes than under the German feed-in tariff scheme across project scales. While the average cost of equity in France is three to five percent higher than in Germany, it is even 11 percent higher in South Africa.

For debt financing in Germany, project developers often use the 'Erneuerbare Energien' program from the KfW (Kreditanstalt für Wiederaufbau) bank. Similar to the cost of equity, the cost of debt is always lowest in the German feed-in tariff system compared to France and South Africa with their tendering schemes. However, country risks might have an additional impact on both cost of equity and cost of debt.

Figure 4.9 shows the weighted average cost of capital for different project scales under feed-in tariffs and tenders. WACC levels were calculated across project scales for the German feed-in tariff and the French tendering scheme (based on equation 4), and reduced by the yields of the respective ten year government bonds, to correct for country risks.

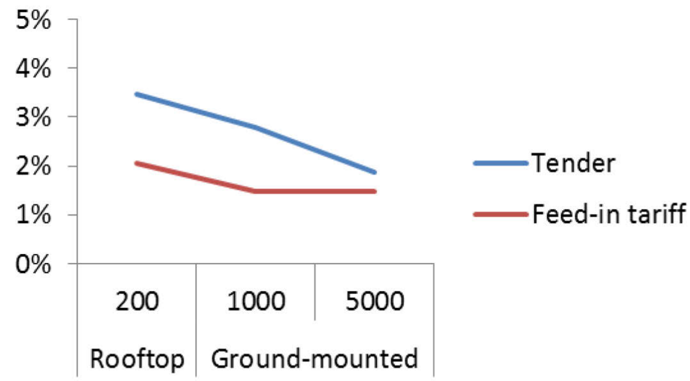


Figure 4.9. Weighted average cost of capital above yields of ten year government bonds, across project scales in the German feed-in tariff and the French tendering scheme

The weighted average cost of capital in the German feed-in tariff system (between 3.2% and 3.7%) is lower than in France (between 4.1% and 5.8%) and South Africa (around 9%) with their tendering schemes. This is due to the lower cost of capital and debt. The yields of ten year government bonds amount to 1.69% for Germany, and to 2.28% for France (Bloomberg, 2014). The corporate tax rate is 29.55% in Germany, and 33.33% in France (KPMG, 2014). The relationship between the national WACC levels also holds without considering the corporate tax rate.

The German feed-in tariff reduces risks in comparison to the French tendering scheme, which leads to lower WACC levels. However, we observe that WACC levels in Germany and France converge for large ground-mounted PV plants.

4.5.3 Transaction costs

The results from the semi-structured interviews revealed the following transaction cost categories being most important for a comparison of tenders and feed-in tariffs:

- Project development times
- Project development costs
- Project implementation success rates
- Innovation barriers
- Costs for bureaucracy
- Costs for the supply chain (in the case of tenders with low frequency)

With regard to overall cost effectiveness, some project developers argued that project development rents are larger in tender systems due to long tender periods and lack of competition, as in general only large companies have the capabilities to participate in tenders. However, private investors are usually pleased with lower returns on their investments in comparison to large companies. But rents may also be higher in feed-in tariff schemes because of higher profit margins due to inadequate feed-in tariff adjustments. In this regard, large-scale installations imply a particularly high risk of overcompensation (excessive rents). Therefore, to carefully equalize profitability across project scales, tenders seem to be more promising for large plants.

As mentioned in section 4.3.2, the focus of this analysis is on the project development phase. Therefore, the following section focuses on the first three transaction cost categories, as (i) interview results allowed to quantify the respective costs, and (ii) they are considered to be of particular relevance for various experts. The other categories are discussed thereafter.

Project development stages and times

PV project development covers the following main development stages: site selection, financing, administrative process, and grid connection permit. Figure 4.10 illustrates a typical project development timeline with individual project steps and sub-categories.

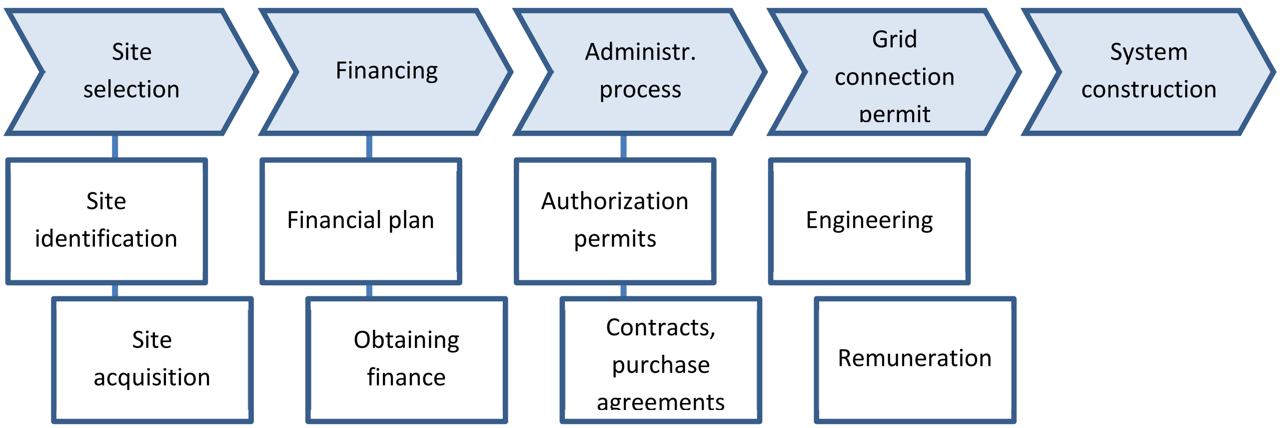


Figure 4.10. Project development stages

Figure 4.11 shows average project development times for PV projects in Germany across size categories. Project development under the German feed-in tariff system takes between 3 to 11 weeks for rooftop PV systems on average, and more than 30 weeks for ground-mounted plants, according to interview results and data from (PVGrid, 2014). The grid connection permit represents the longest process stage for rooftop systems, while the administrative process takes longest for ground-mounted plants.

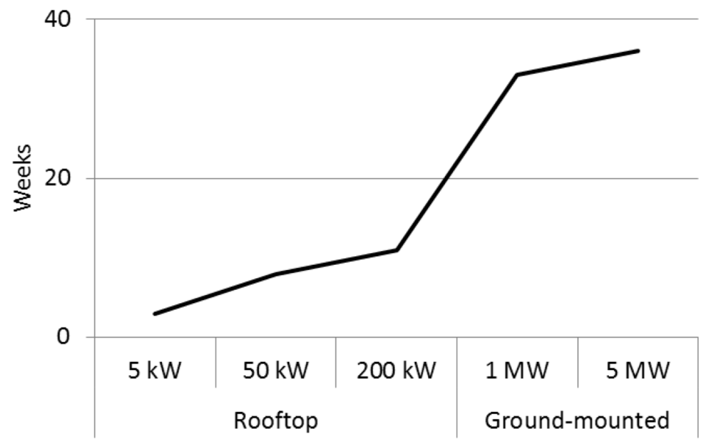


Figure 4.11. Project development times in Germany

Ground-mounted installations imply significantly longer project development times as they need a construction permit in Germany, in comparison to rooftop systems (which need a statics certificate). Project development for ground-mounted systems takes around 9 months, including the arrangement for a land development plan (which can take up to more than a year) and a construction permit (which takes around 12 to 16 weeks). Project developers reported that modules are usually purchased 6 to 8 weeks before system construction. The construction phase takes around 5 weeks. Thus, project developers need planning security for around one year for ground-mounted plants.

Tenders lead to longer project development times in comparison to feed-in tariff schemes, because of the tender time which is related to the additional bureaucracy. Moreover, after winning the tender, there might be less incentives to quickly install the plant than under a flexible feed-in tariff adjustment scheme.

Tenders in France take between 3 months and 4 years, according to expert interviews. The time between filing an application and obtaining a construction permit was reported to be between 8 to 18 months. Before participating in a tender, a project developer gets in contact with module producers and can sign an option contract to reduce risk. After winning a tender sometimes everything gets renegotiated with module manufacturers. As obtaining financing takes around 3 months, modules are usually purchased after about one year. The environmental survey takes around 12 months. After winning a tender, the company has a time period of 18 months to build the plant. For each quarter the company might be delayed with building the plant, the remuneration period (usually 20 years) gets reduced by one month.

Tenders in South Africa were reported to take between 5 months and 2 years, with acceptance of bids occurring three times per year.

Project development costs

Project development costs per installed capacity decrease with increasing system size, as shown by Figure 4.12 for Germany. However, small ground-mounted installations are more expensive to develop than large commercial rooftop systems. This is because project development for ground-mounted plants needs to secure the land and a construction permit. Companies usually finance the project development phase only with equity, and the phases thereafter then also with debt.

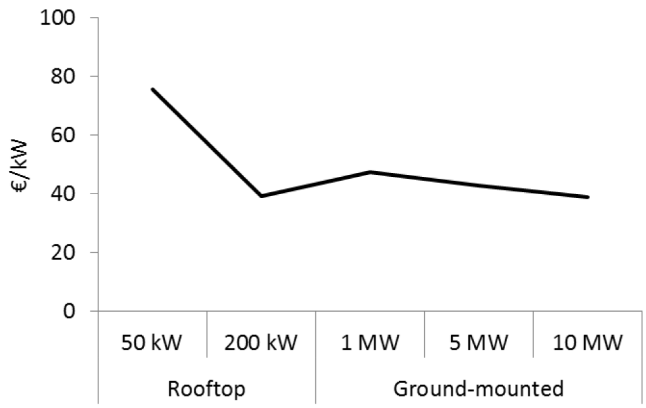


Figure 4.12. Project development costs in Germany

Tenders imply larger project development costs (in comparison to feed-in tariffs) like labor costs for additional documents, costs for collaterals, or marketing costs. In France, additional documents required in tenders include documents for collaterals, on research projects, and CO_2 balance sheets. The tenders in South Africa require an environmental impact assessment, audit reports, guarantees, and a grid compatibility assessment.

Collaterals are usually requested as securities to avoid non-performance. Factors which led to non-delivery after winning a tender were reported to be overestimation of capacities concerning finance and human capital. Project developers reported that collaterals are among the most important transaction costs of tenders.

In the French PV tender 2011/2012 for installations larger than 250 kW an implementation collateral of 50000 €/MWp was required to guarantee implementation of the project (CRE, 2011).[15] Project developers needed to deposit the money for the implementation collateral (corresponding in size roughly to development costs) at the bid with a confirmed bank guarantee for 12 to 24 months, until grid connection and commercial operation. This means that capital requirements for project development double with the collateral.

[15] In this tender also a deconstruction collateral of 30000 €/MWp was required to ensure dismantling of the plant. The deconstruction collateral needs to be deposited for the entire project duration until dismantling of the plant, i.e. for decades. It was reported that banks have difficulties to give money for this collateral type.

Project implementation success rates (and related risks)

In Germany, project development success rates were reported to be around 80 to 90 % for small private systems, around 50% for commercial rooftop systems (with statics and renovation being most critical), and around 20% for ground-mounted systems. Investments in project development of ground-mounted systems are of highest risk because of requirements concerning planning law and ground investigation (land-use plan), as there is no certainty if the project will finally receive construction approval. The main risks are in the administrative process stage. Monthly feed-in tariff adjustments lead to additional planning uncertainty.

Within the current German feed-in tariff adjustment design, companies investing in large-scale projects face uncertain final feed-in tariff rates during the long process of project development. Additionally, there is uncertainty about module prices, and therefore about investment costs. Both uncertainties are correlated and thus expected to partially compensate. Hence, project developers reported that the risks inherent to a tender system outweigh the respective risks under a responsive feed-in tariff scheme.

As tenders imply lower project development success rates, investors need to develop more projects to at least get the chance to implement some of them. In the French PV tender 2011/2012 for ground-mounted installations projects with a cumulative capacity of 1041 MWp applied for a quota of 162.5 MWp. Projects with a cumulative capacity of 183.8 MWp were finally accepted. This is equivalent to a 18% success rate. In South Africa, a 10% success rate between application and winning a tender was reported. This illustrates that in tendering systems companies need to develop several projects to at least get the chance to implement some of them. Moreover, experience with tenders shows that only certain shares of approved projects have actually been realized (see section 4.4.2 for examples).

In the project development phase, the site selection stage has higher risks under a tender, as it is more difficult to get suitable lands due to the lower success rate. The financing stage was reported with a 30-40% higher risk under a tender because of bankability. The administrative process in tenders also usually poses higher risks than in feed-in tariff systems. In the French tenders for installations larger than 250 kW, the price gets only 12 points out of overall 30 points, the rest are environmental and R&D criteria (see section 4.2.2). Project developers reported that there is high uncertainty about why some projects were successful in the French tenders and other were not, as one does not receive a statement about the reasons for the respective decision.

Tenders imply higher uncertainties for project developers than feed-in tariffs. However, as soon as a company wins a tender, risks are lower under the tender (if the contract awarded through the tender includes interconnection and permitting (siting) guarantee) as remuneration rates are secure, so that companies can arrange for bank financing faster. Tenders then can ease financing, if they are well structured, in comparison to flexible feed-in tariff schemes. For banks it is important that the political support scheme secures constant remunerations.

Innovation barriers

According to project developers' experience, tender systems lead to less innovation compared to feed-in tariff schemes. If tenders impose specific technological requirements, companies are restricted in their ability to optimize projects. For instance, one French tender tries to foster innovation by requiring the implementation of tracker systems. To participate, companies must sign a contract for research and development. However, project developers reported that innovation driven by industry itself would be more effective. Tenders impose higher innovation barriers, as policymakers do not have perfect information about technology development. Moreover, long tender periods lead to a delay in technology development. This reduces the speed of the overall transition to a power system based on renewable energy sources.

Costs for the supply chain

Tenders often imply larger challenges for the industrial supply chain. A low frequency or irregular timing of tenders leads to stop and go cycles for industry. In France, tenders were delayed and application criteria were changed in the process, leading to decreasing confidence of project developers and additional challenges for industry. In South Africa, one tender round was cancelled by the government without specifying the reasons.

4.6 Conclusion

While feed-in tariffs are the most common policy instrument to support renewable electricity globally, more European countries apply them for small systems than for large installations, with more tenders being implemented for large-scale plants. Feed-in tariff levels are determined administratively by public authorities, while tendering schemes let investors compete to determine the required remuneration levels. As feed-in tariffs led to an overshoot of planned solar photovoltaics deployment in Germany between 2010 and 2012, automatic tariff adjustment mechanisms have been implemented. However, so far it remains unclear whether these mechanisms work effectively and efficiently for large PV systems.

This paper analyzes the trade-offs for using feed-in tariffs or tenders to support different scales of PV projects. The focus of the analysis is on both deployment effectiveness and specific factors impacting cost effectiveness, in particular financing and transaction costs. To measure deployment effectiveness in terms of achievement of installation targets, the paper develops an analytic model based on quantitative regression analysis to simulate deployment and tariff levels for different project scales in responsive feed-in tariff adjustment mechanisms under various future price scenarios. Semi-structured expert interviews with international project developers result in additional insights about specific factors impacting cost effectiveness under feed-in tariffs and tenders. As most interview partners reported on their experiences with tenders in

France, this study compares cost of capital and transaction costs for the German and French remuneration schemes in detail.

Model results show that responsive feed-in tariff schemes with frequent tariff adjustments are able to reach deployment targets more effectively for small PV systems, while large installations impose additional challenges due to their significantly longer project durations and stronger responsiveness to changes in profitability levels and policy changes. Tenders with set quantities and appropriate incentives to realize successful applications may help to improve target achievement for large-scale plants. However, project implementation success rates largely differ across countries with tenders.

Project developers reported that the risks inherent to tenders outweigh the respective risks under feed-in tariff systems, especially for small projects. From an investor perspective, the current PV feed-in tariff mechanism in Germany with responsive monthly tariff adjustments across project scales imposes higher risks on large installations with longer project durations, as these systems face higher uncertainties about remuneration levels at project completion time. In case of winning a tender, the long-term contract can reduce this type of risk inherent in flexible feed-in tariff adjustment schemes.

Costs of equity and cost of debt are generally lower under feed-in tariffs than tendering mechanisms, while equity shares are relatively similar. Thus, the weighted average cost of capital is significantly lower under feed-in tariff schemes. However, WACC levels calculated based on interview results for feed-in tariffs and tenders converge for large ground-mounted plants, indicating that tendering schemes may be a cost effective alternative for installations above 5 MW in Germany in terms of financing cost.

With regard to transaction costs, tenders lead to longer project development times, higher project development cost, and lower success rates, in comparison to feed-in tariffs. Moreover, tenders often led to higher market concentration, as usually only larger companies with sufficient financial capabilities and reference projects can participate and cope with the complexity of auction mechanisms. In general, the higher transaction costs of tenders seem to be better suited for large plants. When designing tenders, administrative barriers should be kept low, meaning that the amount of required documents to participate should be limited.

There are some limitations of this work which provide areas for future research. First, interview results on cost of capital and transaction costs are based on a sample size of 21 German and French project developers, with the majority being larger companies focusing on commercial and industrial PV systems. It would be interesting to further analyze additional factors impacting cost effectiveness, and to further assess risk evaluations of smaller companies and private investors, as well as project developers across other countries with feed-in tariffs and tenders. Second, while the German Renewable Energy Sources Act (EEG) was introduced in 2000, the French tenders for installations larger than 100 kW were only launched in 2011, meaning that experience with implementation rates and regulatory risks is higher for the remuneration scheme in Germany than for France. Third, the design of tenders largely differs across countries with regard to auction design, evaluation criteria, application processes, frequency, and regional distribution.

Policymakers usually focus on both deployment and cost effectiveness when designing renewables remuneration policies. An overall assessment of the effectiveness of PV remuneration across project scales for feed-in tariffs and tenders depends on the definitions and weightings of both effectiveness dimensions, as well as the framing and calibration of the corresponding indicators and criteria taken into account. In comparison to feed-in tariffs, tenders may improve deployment effectiveness and control on costs to ratepayers under specific circumstances for large projects.

4.7 Appendix

Interview questions

PV project developers

Introduction: Feed-in tariffs have proven to be effective in deploying renewable energy sources. With regard to solar photovoltaics (PV), responsive feed-in tariff adjustment schemes are compatible with quantity targets for small-scale systems with short project durations. However, auction mechanisms may be more suitable for large installations to improve control on costs to ratepayers. The purpose of this research is to find an optimal threshold level between feed-in tariffs and tendering (or quota) schemes.

Disclaimer: Information acquired in this survey will only serve academic research. Your answers will be used confidentially and anonymously. In return for your participation in this interview, we will send you the results of the survey.

1 General questions

- What is your professional position within your company?
- In which major markets is your company active in PV project development? [Germany, Italy, France, UK, USA, China, India, other]
- In which countries do you have most experience with project development under a tendering and a quota scheme respectively?
- In which project stages is your company active? [Development, Construction, Operation]
- What is the size of your firm? [1-9, 10-100, >100 employees]
- What is the average size of your realized projects? [<100 kW, 100-1000 kW, >1 MW]

2 Project development stages

The following process durations (weeks) were identified for different project development stages and system sizes in Germany.[16] Based on your international experience or discussions:

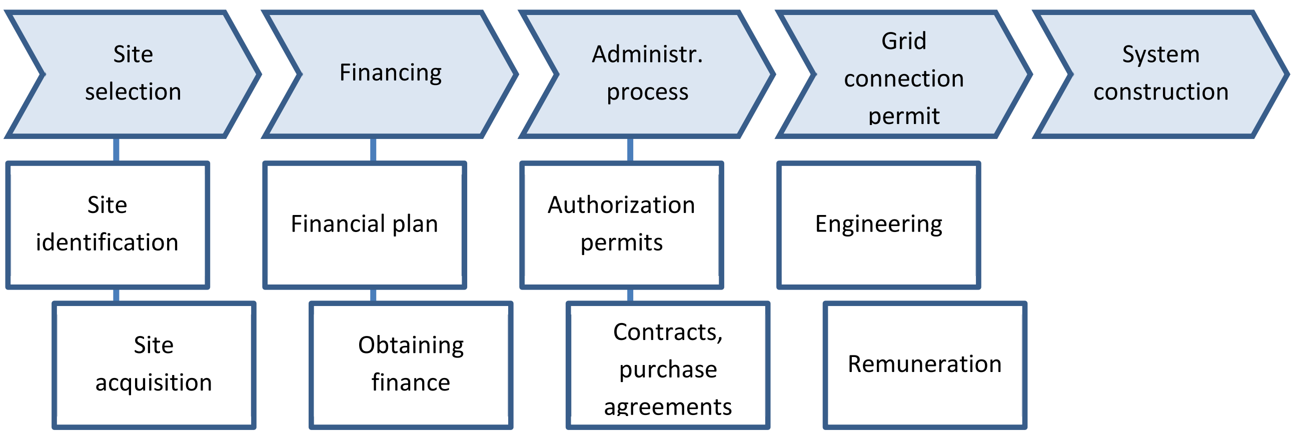
- Do you agree with these values for the case of the German feed-in tariff (FIT)?
- How would these values change in the case of a tender or quota system? If you consider a certain example, please specify the respective country.
- How do you explain the main differences?

[16] PV GRID – project funded by European Commission's Intelligent Energy Europe programme.

	Medium-scale rooftop (50 kWp)			Large-scale ground-mounted (2.5 MWp)		
	FIT	Tender	Quota	FIT	Tender	Quota
Site selection	0			19		
Financing	0			16		
Administrative process	1			36		
Grid connection permit	8			19		
System construction	1			4		

The following project timeline shows development stages with individual sub-categories.

- Do you agree with this project development structure in the case of the German feed-in tariff system?
- How would these categories change in the case of a tender scheme (please specify country)?
- For how long are collaterals usually deposited for a medium- or large-scale project?
- How would the project structure change in the case of a quota scheme?



3 Project risks

There are numerous risk categories associated with the development of a PV project. These risks translate, depending on the type of the remuneration scheme, into different probabilities of project abandonment at each development stage. This section again compares the case of the German feed-in tariff to your previous example of a tender and/or quota scheme.

- What do you consider, according to the following table, to be the main risks and the corresponding probabilities of abandoning a project at each of these stages?
- What is a typical success rate of winning tenders (what share of bids submitted was successful)?

	Feed-in tariff		Tender		Quota	
	Risks	% aban-doned	Risks	% aban-doned	Risks	% aban-doned
Site selection						
Financing						
Administrative process						
Grid connection permit						

4 Project financing and cost of capital

If you have experience with project development under different remuneration mechanisms, please select two of your recent projects with similar size category. If your focus is on one country, please select one recent project. The following questions focus on these specific projects.

- Which year and country where the respective projects commissioned in, and what is the size category?
- The following table focuses on project development (before system construction). What are the corresponding financial indicators for your projects?
- How did cost shares and debt-equity ratios differ across project development stages (site selection, administrative process, etc.)?

	Feed-in tariff	Tender / quota
Budget share spent on development		
Debt-equity ratio		
Cost of equity (return on equity)		
Cost of debt (loan interest rate)		

- If you have experience with tenders, how does the need to deposit a collateral impact your project costs?
- What are other important transaction costs specific to tenders or feed-in tariffs?

Thanks a lot for your comments.

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5 Conclusions

This dissertation with its three self-contained papers aims to contribute to the development and design of effective and efficient policies to remunerate solar photovoltaics power generation. Paper I (chapter 2) explores the technical potential and cost reduction potential of PV, as well as the industry structure and policy framework in Germany and China, and shows the central role of deployment instruments in both countries. Paper II (chapter 3) simulates PV installations for different feed-in tariff adjustment designs in Germany and shows that specific responsive feed-in tariff schemes are able to stabilize deployment for small-scale PV systems. Paper III (chapter 4) demonstrates that large installations are more difficult to manage with flexible feed-in tariff adjustment mechanisms and therefore explores the potential role of tenders for large-scale applications.

In detail, Paper I (chapter 2) finds that building-integrated crystalline solar cells alone could meet around one third of electricity demand projected for 2020 in Germany and China. With ground-mounted installations, PV contribution to electricity supply could increase to about three quarters in Germany and around hundred percent in China (without considering system requirements, in particular electricity storage). While China offers a larger technical potential with its higher solar radiation rates in many provinces, there are lower costs to compete against, as environmental externalities of coal are not yet included in the wholesale power price. The paper shows that PV technology will work on a large scale in both countries if costs are halved, and that costs need to be reduced throughout the value chain, as different components play important roles in overall pricing. This requires further innovation by various actors and across many countries. The comparison of the PV industry in Germany and China in 2009 shows that PV manufacturing capacities are higher in China, while German companies supply more of the production equipment, and that the level of concentration and vertical integration within industry is similar in both countries. The PV industry in both Germany and China has undergone dynamic changes since 2009, with China reaching a sixty percent market share of cells production in 2012 and establishing several companies with manufacturing capacities in the gigawatt range.

The paper shows that deployment support schemes have become extensively used in both Germany and China, and succeeded in enabling PV projects and delivering cost reductions. In Germany, the feed-in tariff scheme has become the main mechanism to deliver PV deployment. The German development bank KfW (Kreditanstalt für Wiederaufbau) provides additional loan programs. PV manufacturers benefit directly (and equipment suppliers indirectly) from investment support measures for manufacturing plants in both China and Germany, including grants, interest-reduced loans, reduced taxes and public guarantees. However, the paper finds that investment support for manufacturing plants has not been sufficiently tied to innovation requirements in neither Germany nor China. The paper also shows that the amount of R&D support has been comparatively weak in both countries. Finally, the paper concludes that the public PV policy debate is increasingly focusing on national industrial policy objectives. In Germany, actors are increasingly concerned that the large PV deployment program of the feed-in tariff 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.

Paper II (chapter 3) reviews the adjustments of the feed-in tariffs for new PV installations in Germany. While the German National Renewable Energy Action Plan from 2010 and the Renewable Energy Sources Act from 2012 target around 3 GW new PV installations per year, annual deployment in 2010, 2011 and 2012 amounted to around 7.5 GW. This shows that setting appropriate feed-in tariff levels for technologies with dynamic price developments is a challenge. As PV system prices declined significantly faster than expected since 2009, feed-in tariffs for new installations were adjusted by several short-term political interventions. Despite the differences between these individual adjustments, the market responded similarly in all cases. In periods preceding feed-in tariff reductions installation volumes always peaked as investors aimed to still qualify for the higher tariffs. Larger projects are more responsive to remuneration level adjustments and policy changes.

Paper II develops an analytic model to simulate the evolution of new PV installations and feed-in tariffs on the basis of observed system prices. This simple model is based on only three factors: (i) deployment increases proportionately with project profitability; (ii) profit expectation of investors decreased over time; and (iii) in periods prior to feed-in tariff reductions, projects are accelerated to still qualify for the higher tariff levels. The paper then focuses on small-scale rooftop systems up to 30 kW as they accounted for around one third of total installations in Germany between 2010 and 2012, and as these projects have relatively short development and construction periods. Simulation results closely match observed deployment volumes and show that private investors with residential systems are able to quickly time their investment decisions in response to price and policy changes. This suggests that the analytic framework has identified the main factors driving investment choices. However, in the future investors might also respond to other factors changing deployment volumes, like uncertainty of policy development.

The analytic model developed in paper II (chapter 3) allows to evaluate feed-in tariff adjustment mechanisms with different degression frequencies, adjustment flexibilities, and qualifying periods. Therefore, the model is used to analyze six different policy designs in five future price scenarios. Simulation results show that responsive feed-in tariff adjustment schemes are suited to stabilize deployment and avoid overfunding, while rigid degression schemes are fraught with risk. Flexible adjustment designs with high degression frequencies can avoid strong pull-forward effects in periods preceding tariff reductions and usually lead to lower deployment than schemes with lower frequency. Flexible feed-in tariff mechanisms with short qualifying periods are fastest in responding to quickly changing system prices.

In Europe, more countries apply feed-in tariffs for small systems than for large installations, with more tenders being implemented for large-scale plants. So far it remains unclear whether the automatic feed-in tariff adjustment mechanism implemented in Germany works effectively and efficiently for large PV systems. Paper III (chapter 4) analyzes the trade-offs for using feed-in tariffs or tenders to support different scales of PV projects. To measure deployment effectiveness the paper uses an analytic model to simulate deployment and tariff levels for different project scales in responsive feed-in tariff mechanisms under various future price scenarios. Semi-structured expert interviews with German and French project development companies result in additional insights about cost of capital and transaction costs for the German feed-in tariff system and the French tendering scheme.

Model results show that flexible feed-in tariff schemes are able to reach deployment targets more effectively for small PV systems, while large installations impose additional challenges due to their longer project durations and stronger responsiveness to changes in profit levels and policy changes. Tenders with set quantities and appropriate incentives to realize successful applications may help to improve target achievement for large plants. However, project implementation success rates strongly differ across countries with tenders. From an investor perspective, the current PV feed-in tariff adjustment mechanism in Germany with flexible monthly tariff adjustments across project scales imposes higher risks on large systems with longer project durations, as these installations face higher uncertainties about remuneration levels at project completion time.

Costs of equity and debt are generally lower under feed-in tariffs than tendering schemes, while equity shares are relatively similar, resulting in the weighted average cost of capital being lower under feed-in tariff mechanisms. However, WACC levels calculated based on interview results for feed-in tariffs and tenders converge for large ground-mounted plants, indicating that tenders may be a cost effective alternative for installations above 5 MW in Germany in terms of financing cost. With regard to transaction costs, tenders lead to longer project development times, higher project development cost, and lower success rates, in comparison to feed-in tariffs.

There are some limitations of this work which provide areas for future research. First, interview results on cost of capital and transaction costs are based on a sample size of 21 German and French project developers, with the majority being larger companies focusing on commercial and industrial PV installations. It would be interesting to further assess additional factors impacting cost effectiveness, and to further analyze risk evaluations of smaller investors. Second, while the German Renewable Energy Sources Act (EEG) was introduced in 2000, the French tenders for projects larger than 100 kW were only launched in 2011, meaning that there is more experience with implementation rates and regulatory risks in Germany than in France. Third, project developers reported that the design of tendering schemes largely differs across countries with regard to auction design, evaluation criteria, application processes, frequency, and regional distribution – it would therefore be interesting to further evaluate experiences with tenders across other countries.

This dissertation shows the importance of solar PV deployment policies in Germany and China, two leading countries in terms of PV installations and manufacturing capacities. The majority of global PV deployment has been driven by feed-in tariffs, which are the most common policy instrument worldwide to support renewable electricity generation. Therefore, this doctoral thesis develops an analytic model to analyze the effectiveness of different feed-in tariff designs and shows that responsive mechanisms with frequent tariff adjustments and short qualifying periods are able to effectively reach deployment targets for small-scale systems. However, large installations are more responsive to changes in system prices and policy adjustments, and hence more difficult to manage with feed-in tariffs. Semi-structured expert interviews with German and French project developers indicate that well-designed tenders with appropriate incentives to encourage competition and to realize successful applications may improve control on costs to ratepayers for large projects.